Improving sustainability in olive oil production by combining AgBalance® with “LifeMax”

Pilot study on olive cultivation

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List of Acronyms

ADP	Abiotic Depletion Potential
ADPe	Abiotic Depletion Potential, elements (resource use minerals and metals)
ADPf	Abiotic Depletion Potential, fossil (resource use energy carriers)
AP	Acidification Potential
BASF	Badische Anilin- & Soda-Fabrik
C	Carbon
CF	Characterization factor
CML	Centre of Environmental Science at Leiden
CPA	Crop protection agent
CTUe	Comparative Toxic Unit for aquatic ecotoxicity
CTUh	Comparative Toxic Unit for human
DM	Dry matter
EEA	Eco-Efficiency Analysis (evaluation method by BASF)
EF	Environmental Footprint
ELCD	European Life Cycle Database
EMEP	European Monitoring Evaluation Programme
EoL	End-of-Life
EP	Eutrophication Potential
EPfw	Eutrophication Potential fresh water
EPm	Eutrophication Potential marine
EPt	Eutrophication Potential terrestrial
ETfw	Ecotoxicity freshwater
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
HTc	Human Toxicity cancer
HTnc	Human Toxicity non-cancer
ILCD	International Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization

JRC	Joint Research Centre
LANCA	Land Use Indicator Value Calculation in Life Cycle Assessment
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
PEF	Product Environmental Footprint
PEFCR	Product environmental footprint category rules
PM	Particulate matter
POCP	Photochemical Ozone Creation Potential
SETAC	Society of Environmental Toxicology and Chemistry
SFP	Smog Formation Potential
SOM	Soil Organic Matter
UNEP	United Nations Environment Programme
VOC	Volatile Organic Compound

Glossary

Life cycle

A view of a product system as “consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal” (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

“Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle” (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

“Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

“Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product” (ISO 14040:2006, section 3.4)

Life cycle interpretation

“Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations” (ISO 14040:2006, section 3.5)

Functional unit

“Quantified performance of a product system for use as a reference unit” (ISO 14040:2006, section 3.20)

Allocation

“Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006, section 3.17)

Closed-loop and open-loop allocation of recycled material

“An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties.”

“A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials.”

(ISO 14044:2006, section 4.3.4.3.3)

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study." (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Comparative assertion

"Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function" (European Commission, 2017).

Dataset

"A document or file with life cycle information of a specified product or other reference (e.g., site, process), covering descriptive metadata and quantitative life cycle inventory and/or life cycle impact assessment data, respectively." (European Commission, 2017)

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, section 3.45).

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Executive Summary

For Molon Lave sustainability is the main strategy that constitutes the most optimal answer to safeguard the viability of their production, their olive groves and their land for the future. With this AgBalance® study on the comparative assessment, Molon Lave takes its sustainability commitment one step further towards the ultimate goal to create a standard based on a combination of AgBalance® with the already existing LifeMax program. The goal of this initial study is to compare the sustainability performance of two different olive grove management systems to identify their weaknesses, their drivers and potential for improvement. A "Benchmark" system portraying the average production situation of Molon Lave in Lakonia, Greece, is compared to the "Sustainable olive grove project farm" located in Lira/Monemvasia, Greece, which uses alternative olive grove management practices.

The assessment is conducted using the AgBalance® method, a holistic method developed by BASF to systematically assess the sustainability performance in agricultural systems. In addition to the quantitative AgBalance® indicators, qualitative questions of the LifeMax certification scheme are addressing biodiversity and social impacts. The final goal of the study is to analyze whether results and findings are sufficiently strong and resilient to potentially develop a sustainability label in combination with the LifeMax findings. This label shall include an environmental, economic, and social assessment as a combination of qualitative and quantitative indicators.

In AgBalance®, the environmental performance is assessed via a cradle-to-field-border Life Cycle Assessment (LCA) with the functional unit of 1 kg fresh olives at field border. Both systems are simulated with primary data, whereas the benchmark data is derived from a production group. In addition to the environmental impact categories recommended by the Product Environmental Footprint (PEF) Guidelines, this study assesses the biodiversity impact of the considered production systems. The used indicator evaluates biodiversity quality by assigning species loss to a certain land use.

The Project Farm differs from the Benchmark by using more and different crop protection agents, irrigating the grove and using more fertilizer to ensure sufficient nutrition. Furthermore, the Project Farm obtains a higher yield per hectare and achieves a higher price per kg olives sold.

In the majority of the assessed environmental impact categories this higher yield results in a lower environmental impact per kg olives for the Project Farm. However, for impact categories that are mainly influenced by the use of crop protection agents (CPA), the Project Farm shows a higher environmental impact, despite the higher yield. This underlines the importance of finding the balance between the applied amount of CPA and the produced yield.

Regarding the economic performance, the Project Farm achieves a higher profit per kg olives due to receiving a higher price for the olives and having lower production costs per kg.

Overall, optimizing the production system towards a higher yield per hectare – best with a similar use of input materials – is environmentally as well as economically beneficial.

So far, the expertise and experience with the LifeMax questions in combination with AgBalance® is still limited. Further steps to interpret the answers in relation to the AgBalance® results will be developed, based on this study. For the creation of a standard based on AgBalance® and LifeMax this study serves as a first step.

Including the further processing steps of the harvested olives should be considered in the follow up study to assess the effect of the farm management practices on the olive oil production.

1 Goal of the Study

This study aims to assess the sustainability performance of different olive cultivation systems by assessing key environmental impacts as well as economic performance characteristics with the BASF AgBalance® method. With AgBalance®, different farming systems can be compared to identify weaknesses, their drivers and potential for improvement. A detailed description of the AgBalance® method and the respective model follows in section 3.2.

In addition to the quantitative AgBalance® indicators, qualitative questions of the LifeMax certification scheme are additionally addressing biodiversity and social impacts.

The project goal is to compare the performance of two different olive grove management systems using the BASF AgBalance® method and LifeMax indicators, focusing on environmental, economic and social impacts to identify impacts, benefits and potential trade-offs of the two systems.

The comparison will be made for a representative grove for conventional practices in this study called "benchmark" and a "sustainable olive grove project farm" that applies alternative management practices. Both systems are simulated with primary data whereas the benchmark data is derived from a production group and not a single farm.

The environmental performance is assessed via a cradle-to-field-border Life Cycle Assessment (LCA) in compliance with the ISO 14040 and ISO 14044 standards.

The target group of this study are on the one hand the producers themselves, but also external stakeholders like consumers buying olive oil made from these olives. For the producers this is an initial assessment of their current practice. With the possibility to compare other production years in the future, it will offer a method to continuously help improving the sustainability performance.

The final goal of the study is to obtain the basis for a sustainability label, which includes an environmental, economic and social assessment using qualitative and quantitative indicators. For the development of the label, the connection between AgBalance® and the LifeMax method still has to be made. The results and findings of this study regarding this connection will be analysed at a later stage, analyzing if they are sufficiently strong and resilient and how the interpretation of the AgBalance® and LifeMax results works together. The study as well as the to-be-developed label shall support promoting a more sustainable production process. Both can be used for training producers and those involved in the production process on environmental protection and biodiversity, new techniques of cultivation, ethical trade issues, and traceability.

As a first phase, this study focusses on the olive cultivation as such. A second phase that also assesses the sustainability performance of the olive oil production is planned.

The results of this pilot study on olive cultivation are intended to be used in comparative assertions intended to be disclosed to the public. An external review panel checks the compliance to the ISO 14040 and 14044 standards for the part of the quantitative environmental assessment as the study results will be one pillar of the prospective sustainability label.

2 Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

The scope definition covers the sustainability assessment of the olive cultivation, so including also economic and social aspects. However, for the sake of compliance to the ISO 14040 and 14044 standards, the study report puts an emphasis on the aspects of the environmental assessment.

2.1. Product System(s)

The cultivation of olive trees (Olea europapaea L.) has a long tradition among some of the European Mediterranean states. Particularly in Italy, Spain and Greece, olive farming has been an important economic branch since thousands of years and contribute to over 90% to today´s olive production in Europe.

The olive tree shows multiple areas of application. Most important is the nutritional aspect through its edible fruits from which oils can be gained with high nutritional value. Furthermore, the oil and also the leaves can be used for the herboristic and cosmetic sectors.

Information on the system boundaries can be found in section 2.3.

In the olive groves, trees produce fruit for further processing starting from an age of 8-10 years from planting. In each year, usually several farming actions take place including fertilization, pruning, soil& weed management, chemical weed control and application of fungicides/pesticides, irrigation and harvest. Not all olive groves follow the same procedures but adjust their farming management to their individual needs.

The sustainable olive grove project farm is located in Lira/Monemvasia, in the region Lakonia South Peloponnese (300 km in south-east direction of Athens). It stretches over approximately 20 hectares. This region represents the second biggest region for Olive production in Greece.

The average producer group "Molon Lave" consists of over 500 producers in 14 villages. The total area is 850 hectares with a yearly production rate of 2500 tons olive oil. More information can be found under www.MolonLave.com.gr. For this study, 5-10 producers of this producer contributed data for the Benchmark scenario.

2.2. Product Function(s) Functional Unit

In accordance with the goal and scope of this study, the chosen functional unit declared for the two production systems in this study is 1 kg of fresh olives at field border representing a season of one year (2019/2020) in Greece, harvested from trees of an average age of 50 years.

Fresh yield was chosen as the functional unit because the final goal of the overall study (not this pilot project) is the assessment of sustainability in olive oil production. The amount of olive oil is mainly correlated to the fresh yield of olives.

Quality parameters of the olives, like size, weight, composition, are not assessed, as the focus lies on the fresh yield. The only difference accounted for is the dry matter content of the olives. The olives produced at the Project Farm have a dry matter content of 35%, whereas it is 40% at the Benchmark. Dry matter contents differ due to irrigation, slightly different times of harvest and differing olive varieties. However, this difference does not impact the results, as the fresh yield is used for the calculations.

The functional unit is associated to the annual production of both assessed olive groves in Greece for a distinct season (2019/2020) and scaled to 1kg fresh olive production.

The reference flow is the same as the functional unit.

2.3. System Boundary

The two considered olive grove management systems are:

1. “Benchmark“: Average production situation Molon Laves groves in Lakonia
2. “Sustainable olive grove project farm “: Alternative olive grove management practices located in Lira/Monemvasia.

For the environmental assessment of the pilot study, the systems are assessed as „cradle-to-field-border“, i.e. starting from extraction of resources from nature and ending to olives harvested. The system includes all activities ‘upstream’ from the extraction of raw materials to manufacturing of the basic intermediate products as well as transportation. For example, in the case of fossil fuel diesel, the system includes all ‘upstream’ activities (extraction of crude oil, refining to diesel and transportation of the diesel to the farm) as well as the combustion of the diesel in the truck or tractor on the farm.

A share of the pruned wood residues leaves the product system and further treatment of the residues is not included in this assessment. The production of the final product olive oil is excluded. Relevant emissions to air, water and soil that occur within the defined boundaries as well as waste management activities are included from the beginning of their respective value chain. A simplified representation of the processes considered in the present study is shown in Figure 2-1.

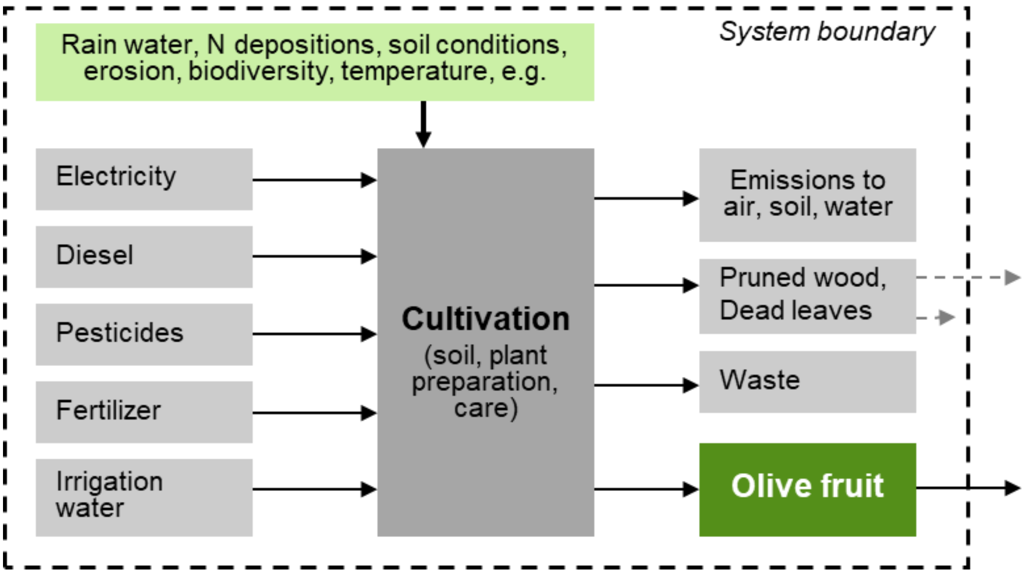

Figure 2-1 System boundary of the assessed cultivation systems

The assessed olive groves are aged over 20 years (mature olive groves), so no effects of land transformation are taken into account. Consequently, establishment and end of life (EoL) of olive trees are not included in the study, due to the long timeframe considered. This is in alignment with the PEFCR (European Commission, 2016a) for olive oils. The manufacturing of infrastructure and capital goods like farm equipment is excluded due to an expected overall low relevance to the results of the environmental assessment. Table 2-1 gives an overview of the elements reflected in the study.

Table 2-1: System elements included and excluded from the system boundaries

Included	Excluded
✓ Nutrient uptake ✓ Biogenic carbon flows ✓ Irrigation ✓ Fertilizer production and application ✓ Crop protection agent (CPA) production and application ✓ Packaging of CPA and fertilizer ✓ Waste management ✓ Transport to farm and field ✓ Soil and weed management ✓ Pruning ✓ Energy production and utilization ✓ Fuel production and utilization ✓ Harvesting	× Establishment of olive trees × Manufacturing of infrastructure / equipment × Incineration of pruning residues × Processing, Use phase and EoL of the final product (olive oil)

The system boundaries for the economic and social assessments differ from the described boundaries applied for the environmental assessment. The final connection between the AgBalance® and the LifeMax method will be carried out at a later stage (e.g., subsequent study). Therefore, the system boundaries for the LCA in this study refer to the AgBalance® method.

2.3.1. Time Coverage

Fruit production follows an annual cycle starting from the next day after harvesting and ending the last day of harvesting in the next year (roughly, but almost never exactly 365 days). This annual production cycle is represented in the pilot study for olive cultivation with harvesting ending in February 2020, while the project farm harvests from October to November and the benchmark farm from December to February.

2.3.2. Technology Coverage

The technology reference is the specific farming technology applied for the selected olive grove management systems - the average technology applied in the “benchmark” system (5-10 producers) and the specific technology applied in the system “Sustainable olive grove project farm”.

2.3.3. Geographical Coverage

The pilot study represents the olive cultivation in Greece, specifically in Lakonia and Lira/Monemvasia.

2.4. Multi-output Allocation

The applied AgBalance® Model does not contain any allocation in the foreground data.

80% of all plant residues from pruning were returned to the field for mulching. The other 20% were used for heating the farmhouses. Because the plant residues are left on the field for mulching, no allocation of environmental burdens or economical income is taken into account. However, nutrient uptake from the pruning residues and the release is reflected to calculate the nutrient balances correctly. Please see section 3.3 for details on modelling of the pruning residues.

For the 20% of pruning residues that are used for heating on the farm, no allocation is applied as well. The nutrient uptakes that leave the system are accounted for in the model.

Allocation of background data (energy and materials) taken from the GaBi (2019) databases is documented online at http://www.gabi-software.com/support/gabi/gabi-database-2019-lci-documentation/.

2.5. Cut-off Criteria

Cut-off criteria are defined for this study for investment goods. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. The treatment of pruning residues that are used for heating on the farm is excluded in this study. No energy substitution is included so no credit for avoided heating energy from the grid is applied.

For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

2.6. Selection of Sustainability Assessment Categories

2.6.1. Environmental impact: selection of LCIA Methodology and Impact Categories

This assessment is predominantly based on the compilation of impact categories recommended by the Product Environmental Footprint (PEF) Guidelines. Implementation in the Life Cycle Assessment software GaBi 9.2 follow the characterization factors EF 2.0 (May 2018) compiled by the European Commission Joint Research Centre.

This collection of indicators applicable for the context in this study include some widely used and respected indicators and LCIA methodologies, e.g. from ReCiPe or CML methodologies, as well as some less known methodologies and others still under debate by the scientific community.

Based on the Product Environmental Footprint Category Rules (PEFCR) by the European Commission (2017) a predefined set of environmental impact categories is used for the analyses of the results in this study, based on the AgBalance® Model. An overview of the impact categories selected for this study as well as the underlying assessment methods can be found in **Table** 2-2. More details are listed in Annex C.

Adaptations to the EF 2.0 impact categories

The category “ionizing radiation” was excluded due to its low relevance for agricultural systems.

For a holistic sustainability assessment of an agricultural system, in AgBalance® covering as many sustainability aspects as possible, biodiversity is included as an additional impact category. The used method in this study was developed by BASF and combines regional characterization factors (CF) from Chaudhary and Brooks (2018) with on-farm management interventions extracted from the Conservation Evidence study (Dicks & Ashpole, 2014). The interventions can be selected in the developed BASF Biodiversity Tool to calculate an action score which then adapts the CF of Chaudhary and Brooks (2018). The CF states species lost per m^2. As the action score leads to a relative adaption of the absolute CF, the unit does not change. This method was developed to account for measure that can be taken in agricultural systems to improve on-farm biodiversity as the CF from Chaudhary and Brooks were calculated for average cultivation systems. More details on the biodiversity assessment are described in section 0.

Land use and climate change are assessed differently compared to the PEFCR. For land use, instead of the LANCA method, the SOM method is used (Brandão & Milà i Canals, 2013). As LANCA requires specific on-farm data which were not available for this study, the SOM method was used due to its simplicity. The SOM method focusses on the life support functions of the soil and refers to the ability of an area to produce biomass (Biotic Production Potential, BPP). The indicator for BPP is organic material in the soil (SOM), which is measured as the soil organic carbon density. The SOM has a direct or indirect influence on the chemical, physical and biological properties of the soil and has a significant impact on the yield of a field

Regarding climate change, the method recommended by the PEFCR was chosen but modified. In contrast to the EF 2.0 carbon change impact category, the uptake and emissions of biogenic carbon dioxide are accounted for in the AgBalance® Model. This is in line with international standards such as the Greenhouse Gas (GHG) Protocol Product Standard (Greenhouse Gas Protocol, 2011), the PAS 2050 specifications for assessment of life cycle GHG emissions of goods and services (BSI Group, 2011) and the ISO 14067 norm (ISO, 2018).

- CF CO2 uptake = 1 (in EU PEF = 0)
- CF biogenic* CO2 emissions = 1 (in EU PEF = 0)
- CF biogenic CO emissions = 1.57 (in EU PEF = 0)
- CFs biogenic CH4 emissions = 36.8 (in EU PEF = 34)

*biogenic emissions refer to flows with "(biotic)" and "non-fossil" in the name.

Carbon fixation, expressed as C content in the crop is considered to have a positive impact on climate change, in case it is stored for a significant period of time (usually more than 100 years). However, this is rarely the case for agricultural products. Therefore, the carbon storage of a crop is accounted for in the inventory, but the sink effect is, by default, excluded from the sustainability analysis.

According to the PEFCR (European Commission, 2017), the USEtox model version 1.01 is used for the three toxicity indicators Ecotoxicity fresh water, Human toxicity cancer and Human toxicity non-cancer. However, in the present study the latest USEtox version 2.12 is used for the emission factors of the pesticide application. The toxicity assessment in LCA is undergoing constant revision as there are high uncertainties to the assessment methods. The characterization of the applied active ingredients has undergone major changes during the evolution of the USEtox model. As the pesticide flows were calculated manually, as described in section 3.3, the most recent version was used. Especially for pesticides, using outdated factors would create high uncertainties.

Table 2-2: Impact categories used for the environmental analysis in the AgBalance® Model based on PEFCR 2017 (European Commission, 2017)

Environmental Impact category	Indicator	Unit	Midpoint LCIA method used in the AgBalance ® Model
Acidification	Accumulated Exceedance (AE)	mol $H+_{eq}$	Accumulated Exceedance (Seppälä, Posch, Johansson, & Hettelingh, 2006), (Posch, et al., 2008)
Climate change [b)]	Radiative forcing as Global Warming Potential (GWP100)	kg $CO_{2\,eq}$	Baseline model of 100 years of the IPCC (based on (IPCC, 2013))
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P_{eq}	EUTREND model (Struijs, Beusen, van Jaarsveld, & Huijbregts, 2009) as implemented in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N_{eq}	EUTREND model (Struijs, Beusen, van Jaarsveld, & Huijbregts, 2009) as implemented in ReCiPe
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N_{eq}	Accumulated Exceedance (Seppälä, Posch, Johansson, & Hettelingh, 2006), (Posch, et al., 2008)
Ecotoxicity, freshwater [c)]	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model, (Rosenbaum R. , et al., 2008)
Human toxicity, cancer [c)]	Comparative Toxic Unit for humans (CTU_h)	CTUh	USEtox model (Rosenbaum R. , et al., 2008)
Human toxicity, non- cancer [c)]	Comparative Toxic Unit for humans (CTU_h)	CTUh	USEtox model (Rosenbaum R. , et al., 2008)
Land use [a)]	Soil Organic Matter	kg C $deficit_{eq}$	Model based on Soil Organic Matter (SOM) (Milà i Canals, Romanyà, & Cowell, 2007)
Ozone depletion	Ozone Depletion Potential (ODP)	kg $CFC\text{-}11_{eq}$	Steady-state ODPs 1999 as in (WMO, 1999) assessment
Particulate matter	Impact on human health	disease incidence	UNEP recommended model (Fantke, et al., 2016)

Environmental Impact category	Indicator	Unit	Midpoint LCIA method used in the AgBalance ® Model
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg $NMVOC_{eq}$	LOTOS-EUROS (Van Zelm, et al., 2008) as applied in ReCiPe
Resource use, fossils	Abiotic resource depletion –fossil fuels (ADP-fossil)	MJ	CML 2002 (Guinée, et al., 2002) and (van Oers, de Koning, Guinée, & Huppes, 2002)
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb_{eq}	CML 2002 (Guinée, et al., 2002) and (van Oers, de Koning, Guinée, & Huppes, 2002)
Water use	User deprivation potential (deprivation-weighted water consumption)	m3 world $_{eq}$	Available Water Remaining (AWARE) (Boulay, et al., 2018)
Biodiversity [d)]	Species loss potential	lost species $_{eq}$	based on (Chaudhary & Brooks, 2018) and (Dicks & Ashpole, 2014)

Legend Table 2-2:

a) Methodology from previous PEF recommendation 2012 (SOM) is used (European Commission & Joint Research Center, 2012).

b) Climate change as recommended in PEF, additionally including biogenic CO_2 assimilations and emissions.

c) The PEF technical advisory board decided that toxicity impact categories are temporarily excluded from the list of impact categories and shall not be officially communicated. However, the toxicity shall be calculated and included in the reports (European Commission, 2017).

d) The novel biodiversity impact category is included in the AgBalance® Model; not a part of the PEFCR 2017 recommendation.

2.6.2. Economic Impact

Profit

Profit is one of the most frequently chosen indicators evaluating the economic performance of the cultivation system for the sustainability analysis within the AgBalance® Model, as farming for profit maximization is a goal that is in line with the economic pillar of sustainability.

The profit (P) consists of the income from sales revenues (R) less the variable costs (TVC) and total fixed costs (TFC) (see Equation 1. With profit, the farm remunerates the capital of the farm and family labor. To calculate this, the farm net value added (FNVA) can be quantified by subtracting the variable costs (TVC) and the fixed machinery costs (FMC) from the total income (In).

Equation 1

$$P = R - TVC - TFC \qquad [€/FU]$$

$$FNVA = In - TVC - FMC \qquad [€/FU]$$

Total cost of production

The total cost of production is the sum of variable and fixed costs, incurred in the production of crops to field gate (Kahan, 2013). This includes costs for energy, fertilizers, crop protection, lease of land, machinery, personnel, water and other costs. In the AgBalance® Model, the variable and fixed costs are further categorized according to the inputs required for farming practices as shown in Table 2-3. The costs for energy, fertilizers, lease of land, crop protection and water are taken from the data collection. The costs for machinery, personnel and other costs are derived from the sum of the respective fixed and variable costs stated in the data collection.

The economic data applied in the AgBalance® Model for this study is listed in section 3.4.

Table 2-3 Categories of total cost of production in the AgBalance® Model

Cost category	Calculation	Type of cost (variable or fix)
Energy cost	EC	Variable cost
Fertilizer cost	FC	Variable cost
Cost of lease of land	LC	Fixed cost
Machinery cost (MC)	$TMC = VMC + FMC$	Variable and fixed costs
Other cost (OC)	$OC = OVC + OFC$	Variable and fixed costs
Personnel cost (OC)	$PC = VPC + FPC$	Variable and fixed costs
Crop protection cost	CPC	Variable cost
Water cost	WaC	Variable cost

2.6.3. Social Impact

The social analysis is an optional feature of sustainability analysis with AgBalance®. Optionality means that the analysis is performed if the social assessment is required within the goal and scope of the sustainability analysis of the farming practices. This is seldom the case for the performed sustainability analysis in the AgBalance® Model. Performing a social analysis is out of scope for the sustainability assessment of the considered olive grove management systems.

However, social indicators are included in this study via the Life Max certification scheme (see section 2.6.4).

2.6.4. LifeMax Indicators

BASF SE and Molon Lave formed a sustainability network, together with the other stakeholders that participate in the "Sustainable Liostasi (Olive grove)" project. The network aims at implementing a new, improved, realistic and sustainable olive cultivation model as a contribution to the olive cultivation sector. The model will respect man, the environment and tradition, next to safety, which is considered prerequisite. All this will be applied while taking advantage of the network's expertise and technology in the agriculture sector with the final goal of an olive oil and/or olives that will carry a special consumer mark. To receive the special consumer mark, inspections and audits of the production from field to shelf have to be conducted. An independent Certification Body is responsible to provide the certification. The receipt of the certificate will be based on the implementation by the producer olive oil mill, olive oil and / or olive production unit of a special protocol named Life Max. The drafting of the protocol was carried out by a team of experts from the technicians involved in the project "Sustainable Liostasi (Olive grove)" under the direction of the company "Aeiforiki SA". BASF is the project manager and owner of the Life Max label.

The implementation of Life Max is based on four pillars: a) Man b) Environment c) Tradition d) Know-how and Technology.

Life Max will be based on:

1. Compliance with European and National Legislation throughout the production process.

2. Compliance with the environmental commitments of this area.

3. Compliance of the principles of food hygiene and safety.

4. Compliance with ethical principles (ethics, well-being and security of staff).

5. Keeping the traceability from the field to the shelf at 100%.

6. Monitoring biodiversity.

7. The monitoring of predefined Critical Control Points.

In this study twelve indicators addressing the compartments biodiversity, soil, product safety and social are included.

Table 2-4 Assessed Life Max indicators

Indicator	Compartment	Unit
Coverage with local varieties % vs. total area	Biodiversity	%
Grass coverage% vs. total area	Biodiversity	%
Number of bird species that use the space of the sustainable olive grove for nesting, feeding or resting	Biodiversity	no
Percentage of land not treated that can be used by wildlife.	Biodiversity	%
Nitrogen surplus	Soil	[kg-N]
Percentage of organic substance in the soil	Soil	[%]
Is the water tested before used (irrigation water, plant protection)	Product safety	yes/no
Number of active substances / sample on final product (harvested olives)	Product safety	[no.]
Number of staff trainings	Social	[no.]
Number of trained staff	Social	[no.]
Protection measures while applying crop protection	Social	yes/no

Table 2-4 shows the choice of LifeMax indicators applied in this study. For the selection of the indicators a mapping between all LifeMax indicators and the AgBalance® method was conducted. Questions already addressed by AgBalance® were not considered, since usually, AgBalance® overachieves the information required by LifeMax by a more detailed analysis of comparable parameters.

2.7. Interpretation to Be Used

The results of the LCI and LCIA are interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

Note that in situations where no product outperforms all of its alternatives in each of the impact categories, some form of cross-category evaluation is necessary to draw conclusions regarding the environmental superiority of one product over the other. This evaluation will take place qualitatively and the defensibility of the results therefore depend on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.8. Optional elements and value choices

Additional analysis made beyond the ISO compliance for environmental assessment:

- normalization of environmental indicators (as included in the AgBalance® concept)
- weighting of environmental indicators (as included in the AgBalance® concept) → value choice (subjective, not scientific-based element)
- economic assessment
- LifeMax analysis for further sustainability aspects.

2.9. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough

transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.

- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in section 5 of this report.

2.10. Software and Database

The AgBalance® Model was created using the GaBi 9 software system for life cycle engineering, developed by Sphera Solutions GmbH. The GaBi 2019 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

The biodiversity assessment was performed using the AgBalance® Biodiversity Calculator (http://biodiversity.northeurope.cloudapp.azure.com/).

2.11. Critical Review

The results of this study will be used by the commissioner (BASF SE). Since in this study, two cultivation systems are directly compared and the results are intended to be disclosed to the public, a critical review has been carried out by an independent review panel according to ISO 14044 (section 6.3).

The critical review process shall ensure that:

- Methods used to carry out the LCA are consistent with ISO 14040 and ISO 14044
- Methods used to carry out the LCA are scientifically and technically valid;
- Data used are appropriate and reasonable in relation to the goal of the study;
- Interpretations reflect the limitations identified and the goal of the study; and
- The report is transparent and consistent.

The critical review panel consisted of:

Prof. Markus Frank, Prof. Konstantinos Stafylidis, Prof. Georgios Nanos

The Critical Review Statement can be found in Annex A. The Critical Review Report containing the comments and recommendations by the independent expert(s) as well as the practitioner's responses is available upon request from the study commissioner in accordance with ISO/TS 14071.

3 Life Cycle Inventory Analysis

3.1 Data collection procedure

Primary data for the year 2019 were collected using customised data collection templates. Conventional olive farming was represented by the average producer group "Molon Lave". For the sustainable olive grove project, data from one specific farm was collected. The data collection templates were sent out by email to the respective coordinating positions.

Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

3.2 AgBalance® Model and its adaptation to this study

The assessment of environmental impacts in olive production is conducted using the AgBalance® Model, which is a specialized tool developed by BASF to calculate the life cycle impact assessment of agricultural systems. Following the concept of Life Cycle Thinking, the AgBalance® Model was developed by BASF in 2009-2010 to assess sustainability in the farming sector, applying principles of the Life Cycle Assessment (LCA) framework (defined by the ISO 14040,14044 and ISO 14045 standards (ISO, 2006a) (ISO, 2006b) (ISO, 2012)). The development is based on the Eco-Efficiency Analysis (Grosse-Sommer, Grünenwald, Paczkowski, van Gelder, & Saling, 2020) with the addition of nutrient balances and biodiversity assessment to offer a comprehensive assessment of the impacts of cultivation systems.

Detailed information on the system boundaries, the model structure and functions of the AgBalance® model can be requested at agbalance@basf.com. However, for means of comprehension, key information is given in this report.

System Boundary

A simplified graphical overview of the AgBalance® model is given in Figure 3-1. It shows the material inputs, farming practices and outputs used and assessed in the model. Each dataset representing an input material contains a full life cycle assessment of the respective input material. If, for example, a certain fertilizer is used as an input, the dataset for this fertilizer contains all environmental benefits and loads from cradle to gate, i.e. from the sourcing and production of the feedstock, the energetical efforts necessary to produce the fertilizer and the packaging. Various farming practices (Figure 3-1) can require the use of fuels. The resulting emissions and other materials leaving the system are considered as output of the cultivation system.

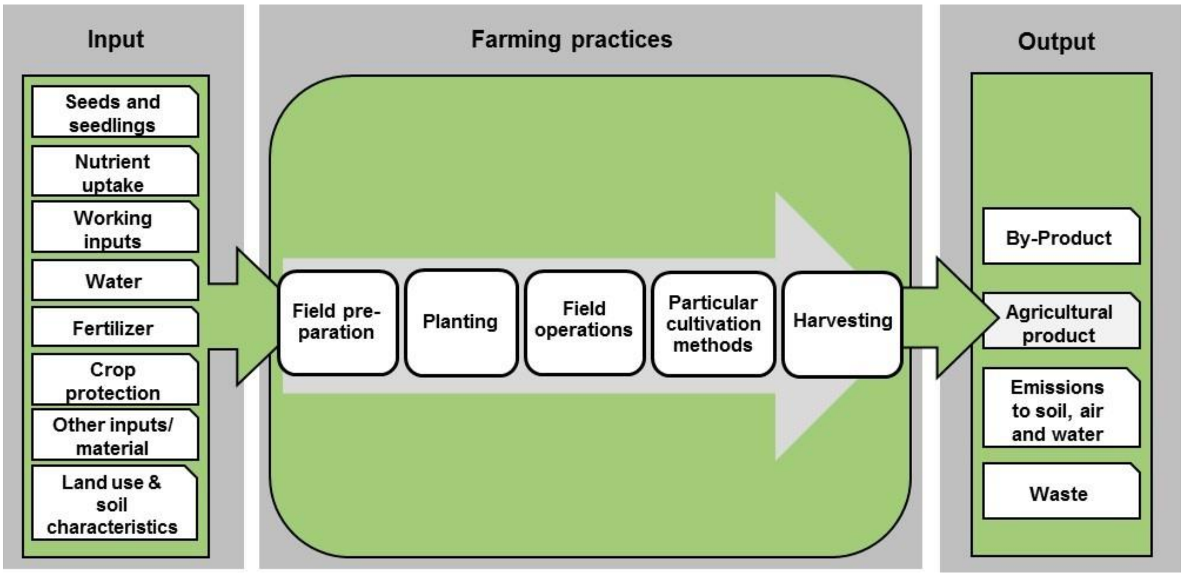

Figure 3-1: System boundaries of the generic cultivation system in the AgBalance® Model

The AgBalance® Model refers to a generic cultivation system, which is in this project adapted to represent a sustainable olive grove project farm and a conventional olive farm. It follows the “cradle to gate” approach, i.e. the assessment includes all processes up to the harvest. In this study, all life cycle stages except the establishment and EoL of olive trees as well as olive oil production are included.

The model for the olive cultivation system includes the necessary elements such as inputs, farming practices and outputs. As inputs and outputs, the following parameters are listed:

Inputs

1. Nutrient uptake
2. Working inputs
3. Water
4. Fertilizers
5. Crop protection
6. Other inputs / material provision
7. Land use and soil characteristics

Outputs

1. Agricultural product specification
2. Agricultural by-products and crop residues
3. Waste
4. Nutrient balance
5. Emissions into air, water and soil

Impact Categories

A predefined set of environmental impact categories is used for the sustainability analysis with the AgBalance® Model. It is based on the guidance of the Product Environmental Footprint Category Rules (European Commission, 2017) by the European Commission (European Commission, 2017). More details can be found in section 2.6.1.

Emissions

The AgBalance® Model covers five main groups of emissions:

1. Nitrogen-based air emissions (NO_x, N_2O and NH_3)
2. Other air emissions (NMVOC, $PM_{2,5}$, PM_{10}, CO_2, CH4, halogenated hydrocarbons, SO_2, Benzpyrene)
3. Heavy metal emissions to soil and water
4. N and P emissions into water
5. Emissions of CPAs into air, water and soil

No direct measurement of field emissions was undertaken in the area under investigation. In order to ensure consistency with other LCA studies, the IPCC Tier 1 emission factors are used (IPCC, 2019). The emission factors applied in the study are as follows:

- GHG emissions arise from the field emissions of N_2O and CO_2. Direct emissions as well as indirect emissions through volatilization are taken into account. Specifically:
  - direct emission of 0.005 kg N_2O-N / kg fertilizer-N
  - direct emission of 0.006 kg N_2O-N / kg N in crop residues
  - indirect emission of 0.05 kg N_2O-N / kg fertilizer-N through volatilized NH_3
  - indirect emission of 0.011 kg N_2O-N / kg fertilizer-N through leached nitrogen (NO_3-N)
- GHG emissions due to land use change (according to IPCC (2019)) are not considered because no land was converted to arable land in the past 20 years in the area under consideration.
- NH_3 emission factors for emissions from mineral fertilizer are taken from EMEP/EEA (2016) (0.067 kg NH_3-N / kg NPK mixture-N, 0,092 kg NH_3-N / kg ammonium sulphate-N)
- NH_3 emission factors for emissions from organic fertilizer are taken from IPCC (2019) (0,21 kg NH_3-N / kg N)
- NO_x emission factors for emissions from mineral fertilizers are taken from Stehfest and Bouwman (2006). (0.011 kg NO-N / kg fertilizer-N)
- Nitrate and Phosphate emission factors to surface water were defined as:
  - 0,0011 kg of the leached nitrogen (NO_3-N)
  - The P-fertilizer factor is calculated according to the formula in Prasuhn (2006)).

The complete list of nitrogen-based air emissions as well as all other field emissions considered in the AgBalance® Model can be found in Annex B. The IPCC recommends different emission factors for wet and dry climates1 as well as aggregated emission factors for certain emissions sources (IPCC, 2019). For this purpose, a climate selector is implemented in the model, to perform an automatic selection and application of the corresponding emission factor. For the present study, the choice in the AgBalance® Model for nitrogen-based emissions is set to “Europe”, and “dry climate”. The choice for Ammonia emissions is set to “normal pH value” and “temperate climate”.

Biodiversity

The use of land for agriculture, in particular mono-cropping systems with intensive input of fertilizers and pesticides, can cause a significant decline in biodiversity in a given landscape of a region. With the intention to estimate the impact of agri-environmental strategies on biodiversity, on-farm, BASF SE developed a tool, combining two approaches:

1. In order to assess the biodiversity footprint in LCA, a characterization model (Chaudhary & Brooks, 2018) was used, which predicts the global potential species loss of 5 taxa[2] per unit of area of 804 ecoregions, for occupation and transformation of 5 land use types and three levels of intensity.
2. The University of Cambridge has summarized evidence from scientific literature about the effects of conservation interventions (Dicks & Ashpole, 2014) to support decisions on how to maintain and restore global biodiversity. Furthermore, an assessment of effectiveness and certainty of these interventions is available in the Conservation Evidence free-access database.

The output of this tool consists of a biodiversity score (in percent) and adapted characterization factors of global potential species loss, based on the interventions taking place on the farm.

In AgBalance®, an agricultural specific biodiversity indicator is used complementary to the ones traditionally used in LCA. This is due to conventional LCA indicators having only a small environmental relevance when evaluating biodiversity at a local level (in this case the field). The regional scope of the conventional LCA indicators is way bigger (e.g. GWP is calculated according to a global model). Hence, these LCA indicators cannot display consequences of farming decisions on local biodiversity.

For the assessment BASF SE developed an Online Tool in which the biodiversity impact can be calculated. The tool may be accessed via http://biodiversity-calculator.basf.com/

3.3 Life Cycle Inventory Data

In this study, the following processes are included:

- Use of agrochemical inputs used (mineral fertilizers, plant protection products)

[1] Wet climates are in temperate and boreal zones where the ratio of annual precipitation to the potential evapotranspiration is higher than 1, and tropical zones where the annual precipitation is higher than 1000mm. The dry climates are in temperate and boreal zones where the ratio of annual precipitation to the potential evapotranspiration is lower than 1, and tropical zones where the annual precipitation is lower than 1000mm. Figure 10A.1 of chapter 10, volume 4 in (IPCC, 2019) provides a map of these climate zones.

[2] The taxa covered by (Chaudhary & Brooks, 2018) include mammals, birds, amphibians, reptiles and plants.

- Use of fuels for farm operations (soil cultivation, pruning, spraying, harvesting) and transportation processes
- Consumption of electricity used for irrigation
- Water consumption
- Auxiliary materials
- Diesel consumption for all mechanical operations taking place during cultivation
- Management interventions for biodiversity enhancement

As described in section 3.1, data for the sustainable olive grove project farm as well as the average producer group were collected. An overview on the data collected can be seen in Table 3-1.

Table 3-1: LCI results for both product systems for 1 ha olive grove

Type	Parameter	Project farm	Benchmark	Unit
Crop	Yield	9771	6500	kg/ha
	Dry matter content	35	40	%
	Carbon content	17,20	19,70	**%**
	Nitrogen content	0,18	0,20	**%**
	P_2O_5 content	0,04	0,05	**%**
	K_2O content	0,33	0,38	**%**
	Lower calorific value	5,48	6,61	MJ/kg
Mechanical operations	Diesel	20	100	l/ha
	Gasoline	60	30	l/ha
Mineral fertilizer	21-0-0 N-P-K		300	kg/ha
	17-10-27 N-P-K	112,50		kg/ha
	10-0-28 N-P-K +10Cao	112,50		kg/ha
	16-8-32 N-P-K	175		kg/ha
	20-20-20 N-P-K	25		kg/ha
Pesticides	Pasta caffaro 38,25sc	3,50	2,10	l/ha
	Imidan 50b WP	2,40		l/ha
	Kelpak	3		l/ha
	Roundup	4,50		l/ha
	Perfektion top 40cc	1		l/ha
	Fastac	0,25		l/ha
Irrigation	Ground water	825		m3/ha
	Electricity	540		MJ/ha

Looking at the collected data, some fundamental differences are visible.

In the referenced year (2019), the sustainable olive grove project farm reached much higher olive yields than the average producer group. The dry matter contents differ between the alternatives as different varieties of olives were cultivated.

Looking at the mechanical operations, diesel consumption for the average producer group is much higher than in the project farm due to the use of heavy soil cultivation machinery, which the project farm does not use. The project farm only carries out weed mowing and pruning mulching, and no soil cultivation machinery.

In contrast to the farms of the average producer groups, the sustainable olive grove project farm had a higher water consumption due to irrigation. The irrigation was necessary due to less rainfall in the region the farm is situated in, especially in the summer months (see Table 3-2). The use of CPA was also higher as well as the amount of working hours. At the same time more fertilizer was applied per hectare in general. Regarding only the nitrogen applied via the fertilizers per ha, the amounts for both alternatives are the same. But considering the applied nitrogen per kg of olives, the sustainable olive grove project farm used less due to the higher olive yield per hectare.

In both farming systems, only mineral fertilization was carried out. No manure was applied except for the mulching.

Table 3-2 Water distribution for the considered farms in the year 2019

	Distribution of irrigation water		Distribution of rainfall	
	mm/ha and month		mm/ha and month	
	Project Farm	**Benchmark**	**Project Farm**	**Benchmark**
January	0	0	219	304
February	0	0	79	75
March	0	0	42	37
April	0	0	67	64
May	8	0	2	7
June	12	0	1	17
July	19	0	2	5
August	19	0	0	4
September	19	0	7	23
October	6	0	25	10
November	0	0	169	126
December	0	0	95	114
Total 2019	**83**	**0**	**708**	**786**

Pruning and mulching

The amounts of residues from pruning differ between the alternatives as different varieties of olives were cultivated and a higher amount available water due to the irrigation, leading to a higher production of fresh weight plant material and accordingly more pruning residues.

80% of all plant residues from pruning were returned to the field for mulching. The other 20% were used for heating the farmhouses and left the system. As these 20% are leaving the field, further treatment of the residues is out of scope. The incineration is not included in this study. Nutrient uptake was considered. However, no allocation was applied as the residues are assumed to have no value. Also no energy substitution is included so no credit for avoided heating energy from the grid is applied.

In the LCA model, the mulching is treated as solid organic fertilizer so decomposition processes and emissions are included for the mulching in the assessment as well. The applied emission factors are stated in Annex B.

Table 3-3 Usage of plant residues from pruning

Plant residues from pruning	Project farm	Benchmark	Unit
Returned to the field (mulching)	8000	4800	kg fresh weight /ha
Leaving the system (heating material)	2000	1200	kg fresh weight /ha
Dry matter content	86,17		%
Carbon content	38,81		%
Nitrogen content	0,76		%
P_2O_5 content	0,23		%
K_2O content	0,41		%

Toxicity

As mentioned in section 2.6.1, the USEtox emission factors for the crop protection applications were adapted manually. The GaBi AgBalance® Model does not provide datasets for specific pesticides, except for glyphosate. For the other crop protection agents generic pesticide and insecticide datasets had to be used. According to the European Commission (2017), pesticide emissions shall be modelled as specific active ingredients. Especially for the toxicity assessment, using the specific CFs is crucial as the differences between them might be extremely high. Hence, the specific CFs were applied to also minimize the uncertainty of the assessment.

As the CF were exchanged manually, in the same course the most updated version of USEtox was used for the calculations. This was due to the rapid developments the toxicity methods are undergoing.

Table 3-4 and Table 3-5 list the values applied for the toxicity emission calculation.

Table 3-4 Active ingredients of pesticides applied in kg per ha

Active ingredient	Project Farm	Benchmark	Comment
Copper oxychloride	0,797	0,4787	Only copper share accounted for
Phosmet	1,2	0	
Glyphosate	1,62	0	
Dimethoate	0,4	0	
a-cypermethrin	0,025	0	

The emissions of each active ingredient are split to 90% emission to soil, 9% emission to air and 1% emission to water as recommended by the European Commission (2017).

Table 3-5 USEtox v.2.12 characterization factors for active ingredients of pesticides

	Death/applied kg			CTUe/applied kg		
Active ingredient	Human toxicity non cancer rural air	Human toxicity non cancer freshwater	Human toxicity non cancer agricultural soil	Freshwater ecotoxicity agricultural soil	Freshwater ecotoxicity air	Freshwater ecotoxicity freshwater
Copper oxychloride	3,51E-05	1,37E-07	1,14E-04	2,97E+04	2,11E+04	5,63E+04
Phosmet	3,51E-07	7,98E-06	4,87E-07	1,09E+04	2,18E+04	1,38E+06
Glyphosate	6,58E-08	1,60E-07	1,16E-07	7,18E+01	6,17E+01	3,21E+02
Dimethoate	7,96E-07	4,16E-06	1,25E-06	1,25E+03	1,35E+03	1,79E+04
a-cypermethrin	1,07E-06	5,17E-06	6,62E-08	4,75E+03	2,52E+05	3,50E+07

USEtox characterizes all active ingredients with “0” for Human toxicity (cancer).

Biodiversity

As stated in section 2.6.1 and 3.2, the biodiversity impact is calculated in a separate Biodiversity Calculator. For the calculations the location of the farms as well as the applied farm management interventions have to be selected.

The ecoregion in which both farms are located is called “PA1201 Aegean and Western Turkey sclerophyllous and mixed forests”. The Characterization Factors (CFs) published by Chaudhary and Brooks (2018) for this ecoregion for “plantation forests” is 9.79 E-14 lost species/m^2. This value is used by the Biodiversity Calculator as basis for both farms as both are located in the same ecoregion and have the same land use type.

The data on field interventions is not sufficiently available because the biodiversity measures stated in the LifeMax questionnaire do not match the available choices in the Biodiversity Calculator. The conservative approach was followed, to not overestimate the on-field interventions due to uncertainty.

According to the LifeMax questionnaire (see section 4.4), the Project farm does more to support biodiversity on their farm.

For the Project Farm, the intervention “manage ditches to benefit wildlife” is chosen, which leads to an action score of 5%. This action score adapts the CF to a species loss/m^2 of 9,75E-14. This intervention appears to be the closest to the actual management practices of the farm.

For the Benchmark no biodiversity interventions are assumed, which leaves the CF at 9,79E-14 lost species per m^2.

The calculated CFs are multiplied with the area needed to produce 1 kg of olives (1,02m^2 for the Project Farm and 1,54m^2 for the Benchmark).

3.3.1 Background datasets

To model the olive grove management system the life cycle inventory background datasets listed in Table 3-6 were used. The list covers all relevant input materials and waste treatment processes to represent the assessed production systems.

Table 3-6 Background datasets used in the GaBi AgBalance® Model

Dataset	Country	Database
Electricity grid mix	GR	ts
Diesel mix at filling station	EU-28	ts
Lubricants at refinery	EU-28	ts
Ammonium sulphate mix (by-product)	DE	ts
Ammonia liquid (NH3) with CO2 recovery, by-product carbon dioxide (economic allocation)	DE	ts
Potassium chloride (KCl/MOP, 60% K2O)	EU-28	ts
NPK: 15-15-15 (nitrophosphate route, 15N-15P2O5, 15K2O) Fertilizers Europe	EU-28	Fertilzers Europe
Raw phosphate (32% P2O5)	EU-28	ts
Lime (CaO; finelime) (EN15804 A1-A3)	DE	ts
Glyphosate production	RER	ecoinvent 3.4
Pestcide average	GLO	ts
Insecticide unspecific (Carbamate 1)	DE	ts
Polyethylene film (PE-LD)	RER	Plastics Europe
Polypropylene Film (PP) without additives	DE	ts
Polypropylene (PP) in waste incineration plant	EU-28	ts
Polyethylene (PE) waste-to-energy plant with dry	EU-28	ts
Tap water from surface water	EU-28	ts

3.4 Economic information

Table 3-7 lists the economic parameters that were used for the economic assessment in the AgBalance® Model. The prices for diesel, electricity, gasoline and water were multiplied with the corresponding amounts stated in Table 3-1. The revenue per kg of olives was multiplied with the yield. The variable costs for personnel was derived by multiplying the hourly rate with the corresponding amount of working hours spent.

Table 3-7 Economic parameters

Position	Project farm	Benchmark	Unit
Revenue of olives	0,61	0,55	€/kg
Price of diesel	1,41	1,41	€/l
Price of electricity	0,46	0,46	€/MJ
Price of gasoline	1,65	1,65	€/l
Price of water	3,00E-07	3,00E-07	€/m³

Position	Project farm	Benchmark	Unit
Costs of fertilizer	530	120	€/ha
Costs of crop protection	187,15	26,25	€/ha
Fixed costs of machinery	200	120	€/ha
Other variable costs	200	150	€/ha
Fixed costs of personnel	800	1240	€/ha
Hourly rate of a permanent	4	4	€/h
Hourly rate of a seasonal worker	5	5	€/h
Working hours spend by a permanent worker	160	170	h/ha
Working hours spend by a seasonal worker	190	130	h/ha
Total subsidies received per agricultural area	800	800	€/ha

The values for the olive revenue may be overestimated. Since the planned functional unit of the overall study is the olive oil, the actual prices of the olives are not available. To obtain the olive revenue, the final price of the produced olive oil was allocated back to 1 kg of fresh olives entering the olive oil mill. This means, that the production costs of the olive oil are incorporated in the stated revenue. The actual virtual revenue for olives is assumed but be a little bit lower. As the specific production costs are not available for this study, the uncertainty to estimate a virtual revenue for the olives was too high. The relative difference between the stated revenue and the actual virtual revenue is supposed to be the same for both alternatives. Hence, the only effect this assumption has, is a small uncertainty in the profit results.

4 Results

A complete list of indicators assessed in the course of the study and the underlying assessment methods can be found in section 2.6.1.

The results for the total costs of production (section 4.1.2) as well as the environmental indicators (section 4.1.4-4.1.19) are divided into the different elements of the cultivation system. The accounted for elements are as follows:

- CPA provision: the production and transportation of the crop protection agents (all background processes accounted for)
- Energy provision: electricity generation and fuel production (all background processes accounted for)
- Fertilizer provision: the production and transportation of the fertilizers (all background processes accounted for)
- Field activity: all emissions that occur on the field by applying fertilizers and CPA, as well as emissions from diesel combustion and land use
- Other input provision: production and transportation of packaging materials from fertilizers and CPA – EoL treatment of those materials is included
- Seed provision: this element is a default category in the AgBalance® results graphs but does not apply for this study
- Water provision: water used for irrigation and dilution of pesticides

4.1 AgBalance® Results

The detailed results for all AgBalance® indicators are shown in the sections 4.1.1-4.1.19.

This chapter contains the results for the environmental impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

The environmental impact potential per kg olives is lower in many impact categories for the Project Farm. The environmental impact per area is divided by a larger amount of olives produced, resulting in lower values on a unit production basis. This implies as well that a smaller area is needed to produce 1kg of olives on the Project Farm. This "yield-effect" can be seen in the impact categories Acidification Potential (AP), Climate Change (Global Warming Potential, GWP), Eutrophication marine (EPm), Eutrophication terrestrial (EPt), Human toxicity cancer (HTc), Land use (LU), Particulate Matter (PM), Photochemical Ozone Creation Depletion (POCP), Resource use energy carriers (Abiotic Depletion Potential fossil, ADPf) and Biodiversity.

The above described "yield-effect" is diminished for freshwater eutrophication (EPfw), freshwater ecotoxicity (ETfw), Human toxicity non-cancer (HTnc), ozone depletion potential (ODP) and resource use minerals and metals (ADPe). For those impact categories, the effect of a higher yield is levelled out by the higher amount of crop protection agents (CPA) used.

4.1.1 Nutrient balance

The nutrient balance in Figure 4-1 shows no nutrient deficit for the Project Farm. The nitrogen and phosphate balances are almost closed, whereas the potash balance shows a high surplus per kg olives. The Benchmark has a twice as high nitrogen surplus than the Project Farm. The higher nitrogen surplus of the Benchmark reinforces the “yield-effect” for EPt and EPm. The phosphate deficit on the other hand reduces the yield effect for EPfw, as the Project Farm applies more phosphate, which leads to more phosphorus emissions. The Benchmark shows a high potash deficit per kg olives.

This nutrient balance is a simplified visualization and only includes the direct input and removal of nutrients into and from the system. For the balance, the nutrients uptake of the crop is subtracted from the total amount of nutrients applied by fertilizers. Nitrogen based emissions that are reducing the nutrient stock in the field are not included in this graph. However, for the LCA all emissions, other nitrogen inputs and nitrogen losses like leaching are included in the calculation.

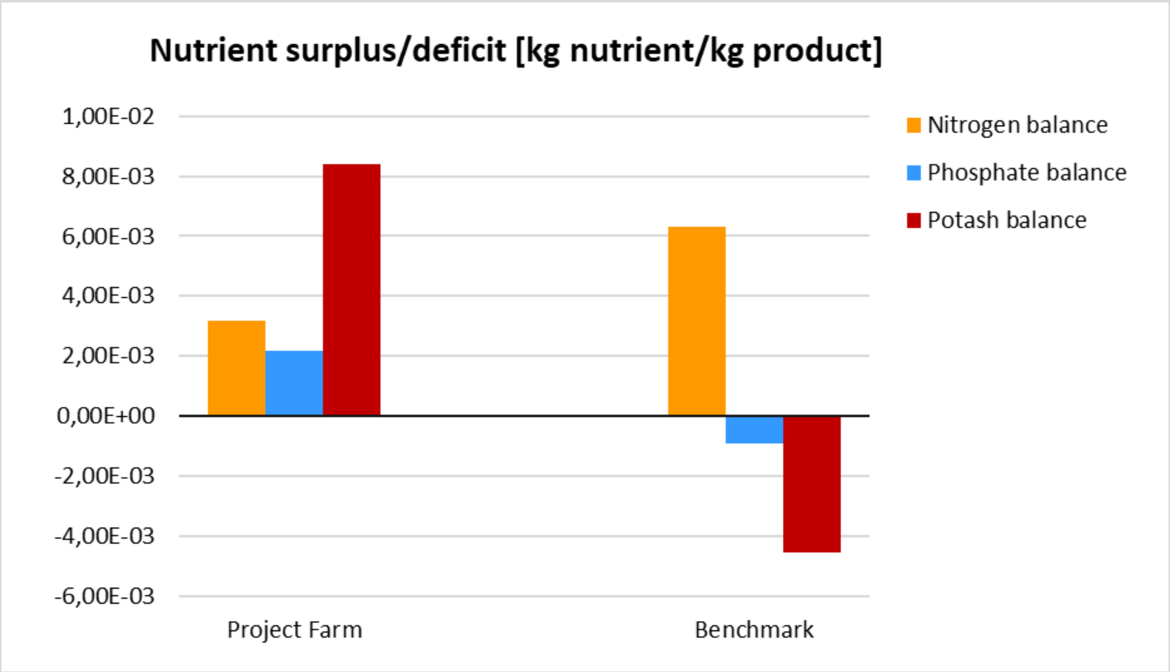

Figure 4-1 Nutrient surplus and deficit per kg of olives for nitrogen, phosphate and potash

4.1.2 Total cost of production

The income per kg olives is almost even for both farms. The Project Farm has a higher sales revenue. The Benchmark on the other hand, has higher income subsidies per kg olives as those are paid per ha, and the Benchmark needs more area to produce 1 kg of olives. For both scenarios the highest cost position is personnel costs (see Figure 4-2). However, all cost positions per kg olives are lower for the Project Farm, which leads to a higher profit of around 0,11€ per kg of olives (see Figure 4-3).

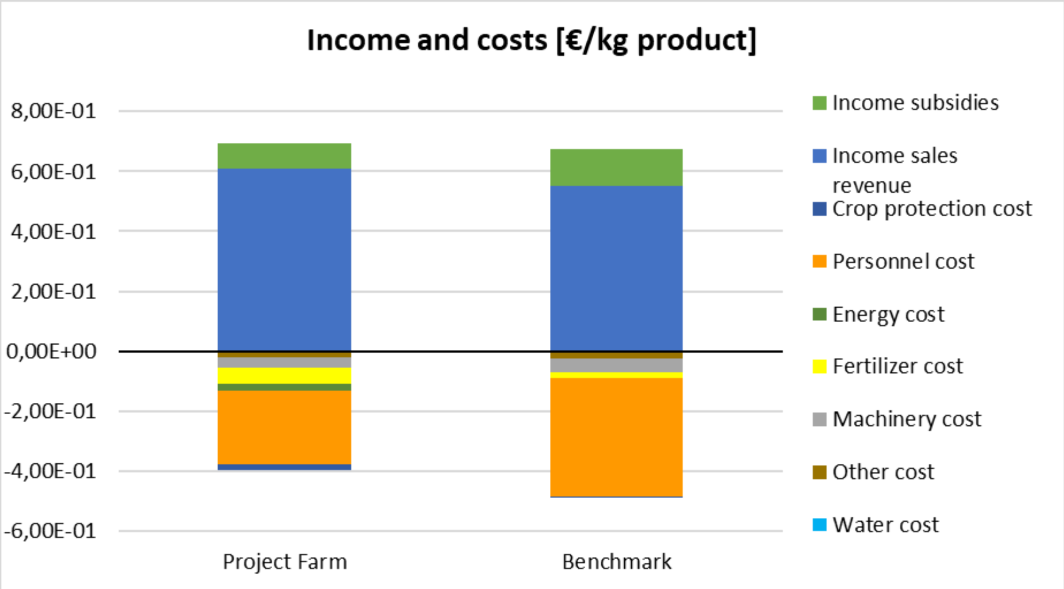

Figure 4-2 Income and cost positions broken down per kg of olives

4.1.3 Profit

Due to the higher sales revenue and lower costs for personnel of the project farm, the profit is also higher (~40 %).

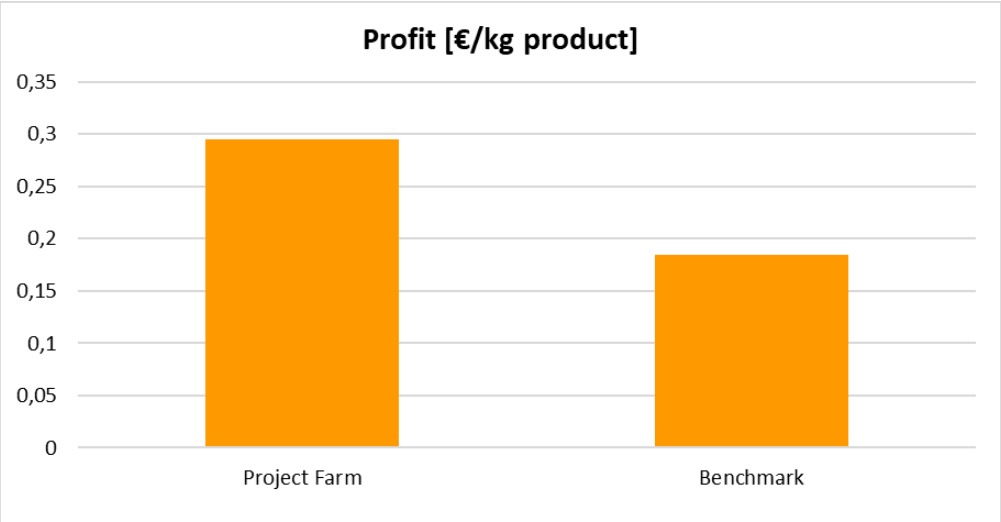

Figure 4-3 Profit per kg of olives

4.1.4 Acidification

The Project Farm has a 25% lower AP than the Benchmark. AP is dominated by fertilizer induced ammonia (NH_3) emissions for both considered farms (see Figure 4-4).

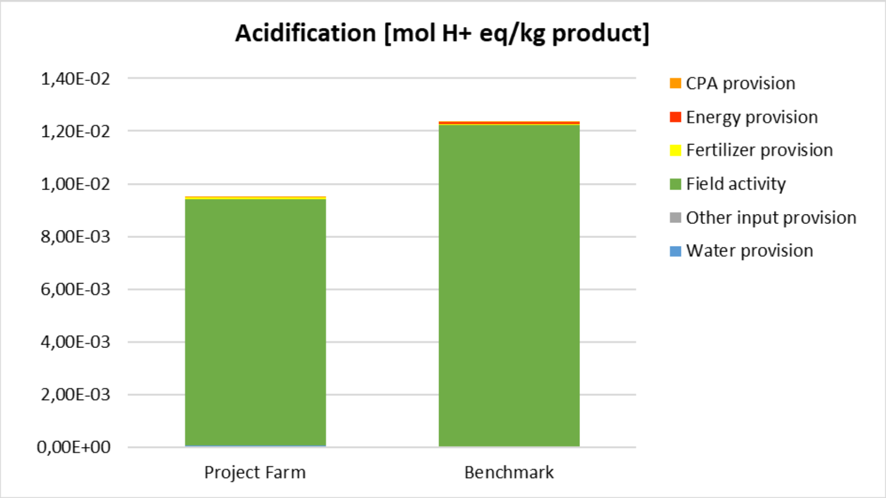

Figure 4-4 Acidification potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.5 Climate change

The GWP is dominated by emissions from nitrification and denitrification as a result of N fertilizer application (47%) for the Project Farm. Emissions from fertilizer production (28%) are the second largest contributor. The energy demand for irrigation contributes 13% to the GWP of the Project Farm (see Figure 4-5). The Benchmark shows the same emissions from fertilizer application, which dominate significantly with 74% and only 17% of the GWP derives from the fertilizer provision. Despite a higher impact from fertilizer provision and additional emissions due to irrigation, the total GWP for the Project Farm is around 16% lower than the Benchmark.

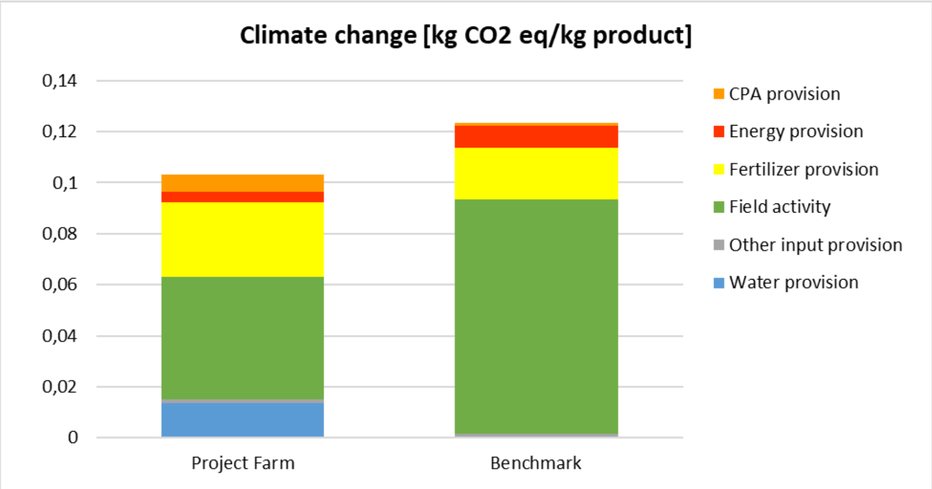

Figure 4-5 Global warming potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.6 Eutrophication freshwater

For the Project Farm EPfw is driven by phosphorus based emissions from fertilizer application that are assessed in the category “Field activity” (71%) and CPA provision (27%) as is shown in Figure 4-6. The impact from CPA provision is mainly driven by the glyphosate production and therefore not existing for the Benchmark. As stated in section 3.3, for glyphosate a specific dataset is used, whereas the other CPA are represented by a generic dataset. This allows to identify the impact of the glyphosate production separately. Due to the higher impact from CPA provision, the total EPfw of the Project Farm is around 10% lower. For the Benchmark, EPfw is almost completely driven by phosphorus-based emissions from fertilizer application.

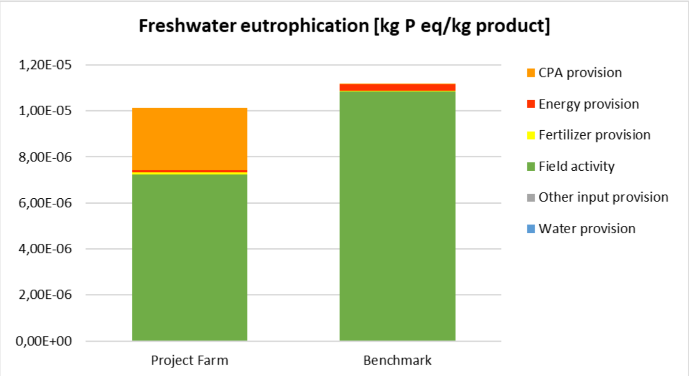

Figure 4-6 Freshwater eutrophication potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.7 Eutrophication marine

Nitrogen based emissions from fertilizer application are the main driver for EPm and EPt in both scenarios (see Figure 4-7 and Figure 4-8). For both impact categories the nitrogen surplus of the Benchmark identified in section 4.1.1 amplifies the “yield-effect” leading to a 71% lower impact for the Project Farm. The impact category EPm represents the degree to which the emitted nutrients reach the marine end compartment. As both plantations are not located close to the ocean, the results of this impact category are of minor importance for the assessment.

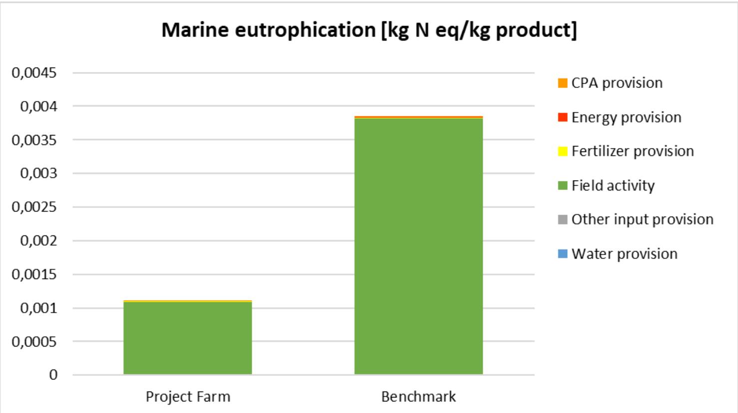

Figure 4-7 Marine eutrophication potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.8 Eutrophication terrestrial

As stated in section 4.1.7 the main driver for EPt and EPm are the nitrogen based emissions from fertilizer application that are assessed in the category “Field activity”. The Project Farm has a 24% lower impact in EPt compared to the Benchmark.

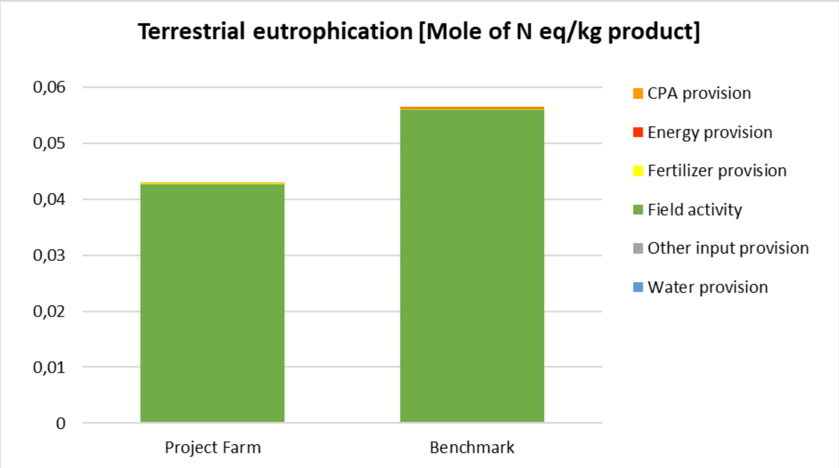

Figure 4-8 Terrestrial eutrophication potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.9 Freshwater ecotoxicity

Freshwater ecotoxicity is dominated by the emissions of CPA application as described in chapter 3.2. The Project Farm has an ETfw around twice as high as the Benchmark (see Figure 4-9), which results from the amount and kind of CPA used.

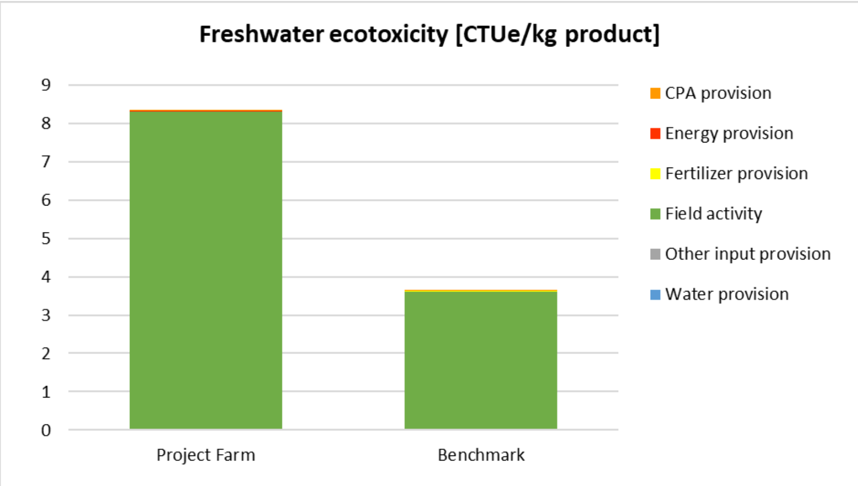

Figure 4-9 Freshwater ecotoxicity potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.10 Human toxicity cancer

The HTc impact is around 13% lower for the Project Farm. The Project farm applies more fertilizer which is shown in the field emissions (mainly heavy metal emissions). However, for the energy and fertilizer provision impacts, the higher yield of the Project Farm results in a lower toxicity profile. The impact of energy provision for the Benchmark is driven by the fuel used for the field management.

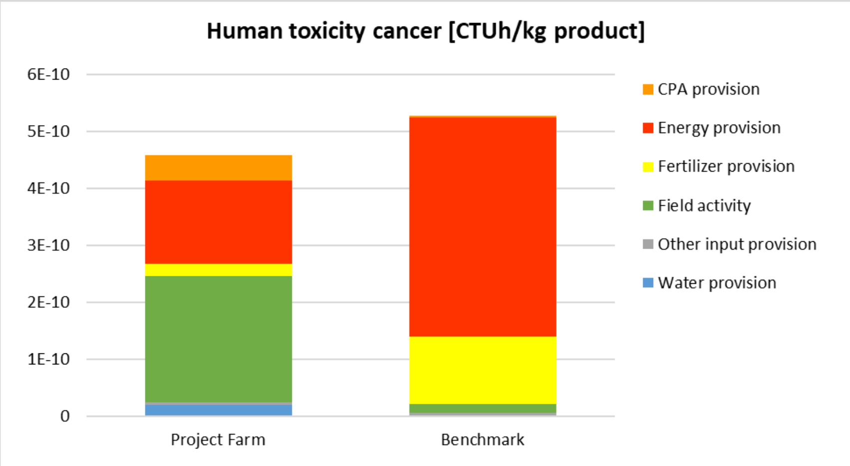

Figure 4-10 Human toxicity (cancer) potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.11 Human toxicity non-cancer

Like freshwater ecotoxicity the category human toxicity non-cancer is dominated by the emissions of CPA application as described in chapter 3.2. The Project Farm has a CTUh around nine times as high as the Benchmark (see Figure 4-11) which results from the amount and kind of CPA used.

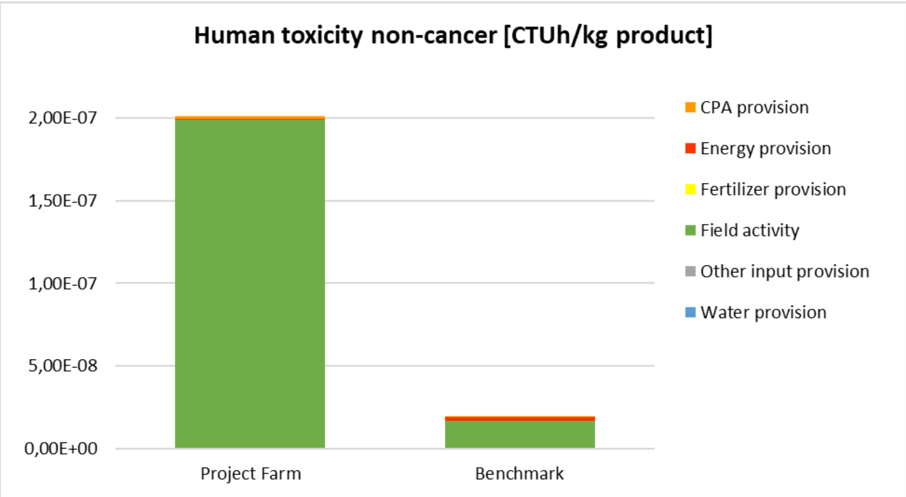

Figure 4-11 Human toxicity (non-cancer) potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.12 Land use (SOM)

For the LU impact the above stated “yield-effect” is the primary driver, as on the Project Farm a smaller area is used to produce 1 kg of olives. LU impact is 34% lower for the Project Farm.

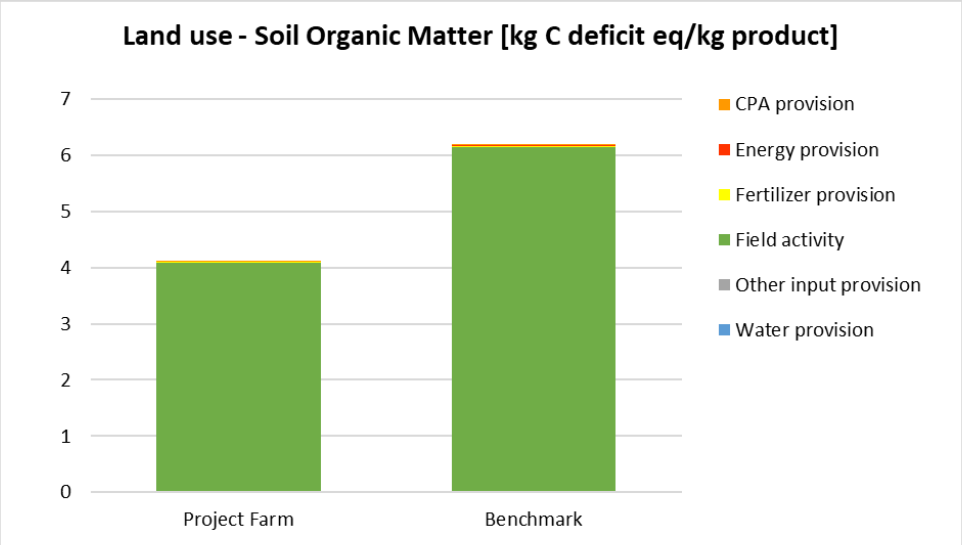

Figure 4-12 Land use impact per kg of olives at field border - breakdown by elements of the cultivation system

4.1.13 Ozone depletion

ODP is driven by the CPA provision itself, whereas the main impact is derived from the glyphosate provision (see Figure 4-13).

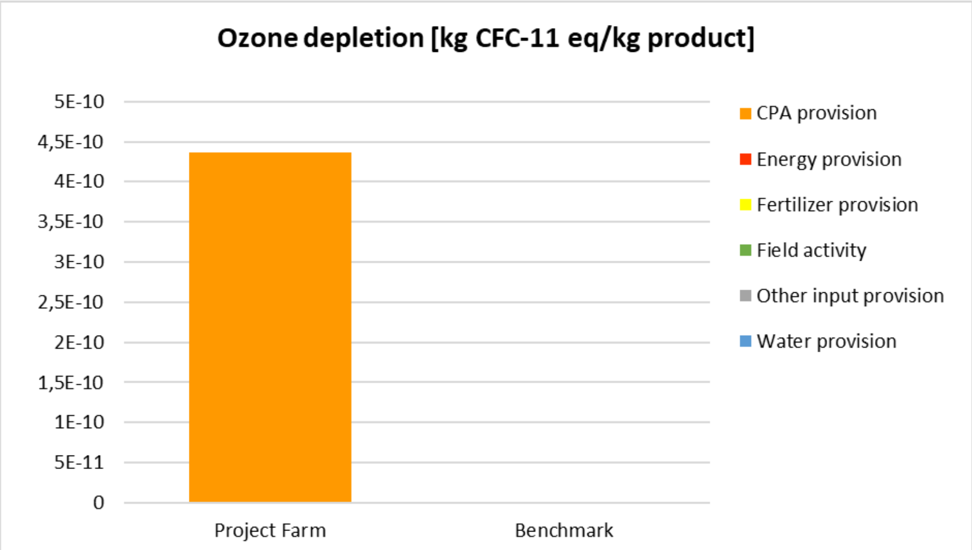

Figure 4-13 Ozone depletion potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.14 Particulate matter

The in Figure 4-14 shown emissions from field activity for the Particulate Matter impact (PM) are dominated by nitrogen-based emissions from fertilizer application as well as dust emissions due to land use. The Project Farm has a 28% lower impact for PM than the Benchmark.

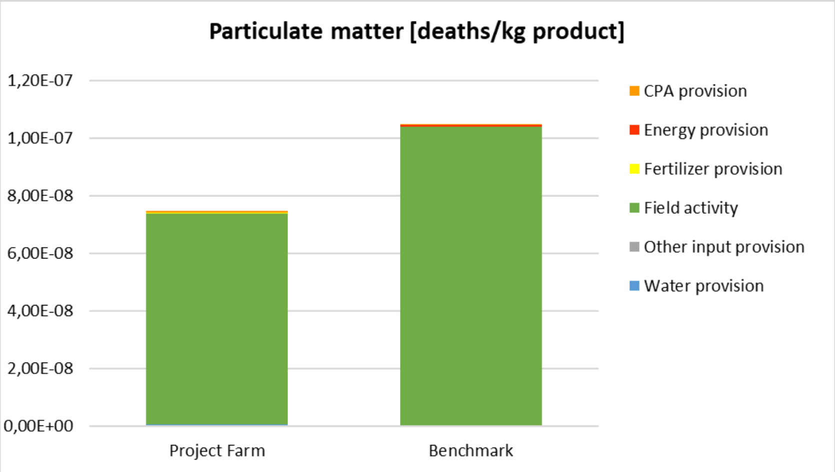

Figure 4-14 Particulate matter impact per kg of olives at field border - breakdown by elements of the cultivation system

4.1.15 Photochemical ozone formation

The POCP for both scenarios is derived from the field activity. However, the drivers for this impact category are different for both systems. For the Project Farm 15% of the POCP come from tractor emissions, 15% are NMVOC emissions due to land use and 60% are nitrogen-based emissions from fertilizer application. For the Benchmark 55% of the POCP are derived from tractor emissions, 10% are NMVOC emissions due to land use and only 30% are nitrogen based emissions from fertilizer application. The total POCP for the Project Farm is 47% lower than for the Benchmark.

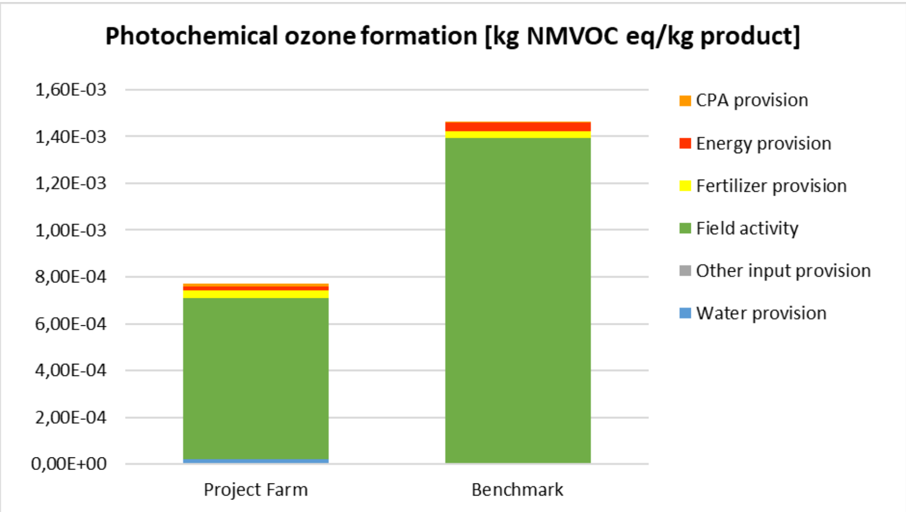

Figure 4-15 Photochemical ozone formation potential per kg of olives at field border - breakdown by elements of the cultivation system

4.1.16 Resource use: energy carriers

According to Figure 4-16 the resource use of energy carriers (ADPf) is around 15% lower for the Project Farm as the fuel demand per kg of olives is higher for the Benchmark.12% of the ADPf of the Project Farm derive from the energy demand for irrigation, which is included in the category "Water provision".

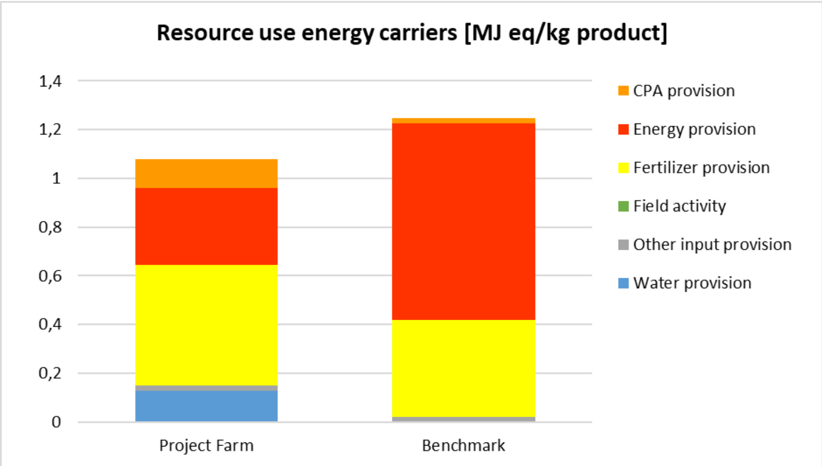

Figure 4-16 Resource use (energy carriers) per kg of olives at field border - breakdown by elements of the cultivation system

4.1.17 Resource use - minerals and metals

ADPe is driven by the CPA provision, whereas the main impact comes from the glyphosate provision (see Figure 4-17). As stated in section 3.3, for glyphosate a specific dataset is used, whereas the other CPA are represented by a generic dataset. This allows to identify the impact of the glyphosate production separately. The Project Farm has a 45% higher ADPe impact than the Benchmark.

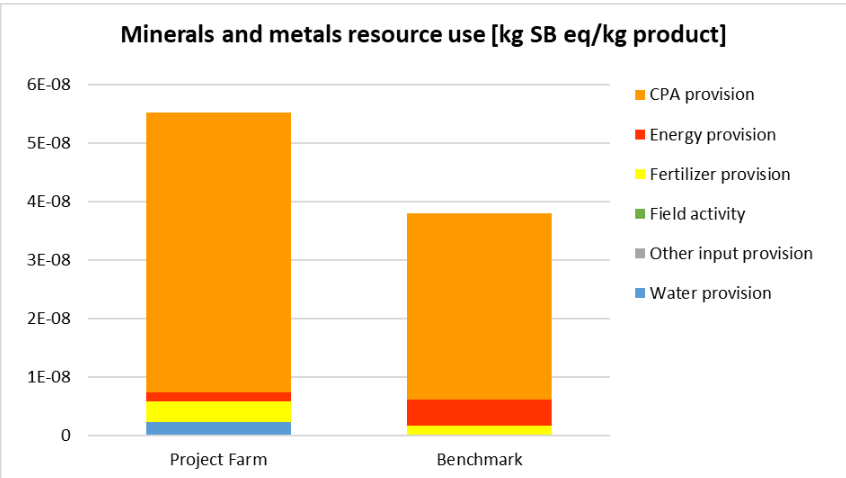

Figure 4-17 Resource use (minerals and metals) per kg of olives at field border - breakdown by elements of the cultivation system

4.1.18 Water scarcity

The water scarcity impact is driven by the applied irrigation. As the Benchmark does not irrigate, it shows no impact in this category. The Project Farm uses 84 litres of water per kg olives, while the applied scarcity factor is 0,068 m^3 world equivalent per litre of water.

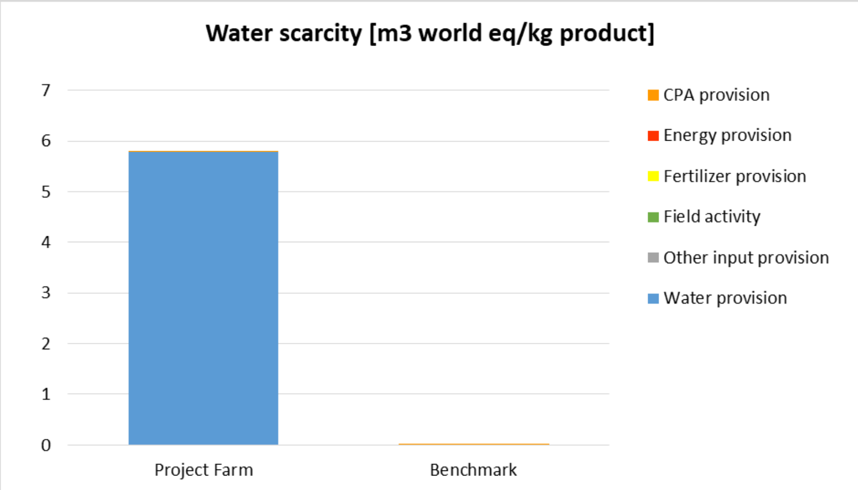

Figure 4-18 Water scarcity impact per kg of olives at field border - breakdown by elements of the cultivation system

4.1.19 Biodiversity

Regarding the biodiversity impact, the "yield-effect" shows its full impact (see Figure 4-19). As in the biodiversity calculator of BASF field interventions are regarded as having a minor impact on improving overall biodiversity, both scenarios show similar results. The determining value for the biodiversity assessment is the Characterization Factor developed by Chaudhary given in species loss per used m^2 (Chaudhary & Brooks, 2018). As both scenarios are located in the same ecoregion, this value is identical. The biodiversity impact on the Project Farm is around 35% lower than the Benchmark.

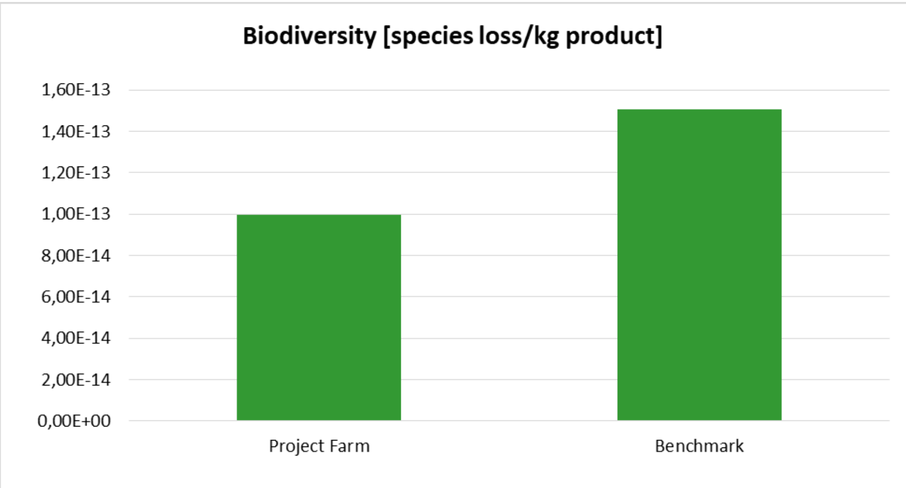

Figure 4-19 Biodiversity impact per kg of olives at field border - breakdown by elements of the cultivation system

4.2 Normalization and weighting

In this chapter the optional element of weighting is described, which lies beyond the ISO compliance for environmental assessment. Despite the scientific approach and foundation that was applied to develop the weighting scheme, weighting in LCA is considered to be based on subjective value choices.

In the AgBalance® Model, normalization and weighting are chosen to aggregate the results. The basis for the weighting and normalization of the LCA results is the PEF weighting and normalization scheme from the European Commission (2017).

Normalization helps in understanding the relative magnitude of the impact associated with a product, when compared to a reference value per impact category (ISO, 2006b). As for the land use normalization value, it is based on the global normalization factor reported in (Benini, Sala, & Pant, 2015) and (GreenDelta GmbH, 2017). To account for the biodiversity impact, a yearly average of number of species[3] gone extinct (IUCN, 2019) is used as normalization factor and is integrated in the normalization scheme of the AgBalance® Model.

For the normalization of the economic LCIA result, the profit is normalized with the global gross domestic product (GDP) per capita from the Word Bank Database of year 2018, equivalent to 8207,75 €.

A weighting scheme is used to define the relative importance of the impact categories among each other and to enable aggregation of all LCA results into a single score. Taking also into account the scientifically robustness of the method used.

As mentioned above, the initial weighting scheme used is the PEF weighting scheme, which was adapted to include the biodiversity impact category and exclude the ionizing radiation impact category. To include biodiversity, the importance of this indicator had to be identified. According to the concept of the Planetary Boundaries climate change and biodiversity rank on the same level of importance for life on earth (Steffen, et al., 2015). Following this in the AgBalance® model the weighting factor was allocated equivalent to that of climate change.

Weighting factors are not only developed by assigning a value to the importance of an indicator. Additionally, the used impact methods are evaluated with regards to their robustness. An impact category that is assessed using a standardized and scientifically accepted method has a higher robustness factor than a method to assess an impact category that is still under discussion and not broadly approved. Hence, the robustness factors are parameters that assess the reliability of results of each impact category (Sala, Cerutti, & Pant, 2018). Again, the values provided by the European Commission (2017) were used as a basis. For the biodiversity category, a robustness factor was developed, according to the methodology for the development of a weighting approach for the Environmental Footprint by Sala, Cerutti and Pant (2018). The calculation and development of the robustness factor was conducted by an expert panel. The panel consisted of internal and external LCA experts as well as internal biodiversity experts. Following the approach to define a robustness factor from Sala, Cerutti and Pant (2018), each expert had to evaluate the same three aspects of the biodiversity method. The aspects are completeness, normalization and recommendation. Completeness refers to how well possible impacts are covered in the biodiversity

[3] The list of extinct species was filtered to include the same taxa covered by (Chaudhary & Brooks, 2018): mammals, birds, amphibians, reptiles and plants.

assessment method. Normalization refers to how well the reference impact of the method is assessed in the methodology. Recommendation addresses the expert's opinion in how far the method can be applied and what level of improvement and caution has to be taken. The scoring of the three aspects contribute equally to the final robustness factor.

The robustness factors of the environmental assessment methods are multiplied with the importance that was assigned to them to receive the final weighting factor. This explains why climate change and biodiversity have different weighting factors although the same importance was assigned to them (see Table 4-1).

Furthermore, the weighting factor of the ionizing radiation category was excluded due to the low relevance of this category in agricultural systems. The remaining scheme was scaled back to 100%. It needs to be stated that the resulting weighting factors as of Table 4-1 do not fully reflect the impacts that intensive agriculture has on the environment, in particular with respect to water scarcity, freshwater ecotoxicity and eutrophication. The assessment method of freshwater toxicity has an admittedly low robustness and eutrophication is an important impact especially for annual crops.

The final AgBalance® weighting scheme is shown in Table 4-1.

Table 4-1 The default normalization and weighting scheme in AgBalance® Model for all midpoint impact categories

Environmental impact categories	AgBalance® normalization scheme (per person)	AgBalance® weighting scheme
	[person eq $^{-1}$]	%
Profit [EUR]	8,21E+03	100%
Acidification [Mole of H+ eq.]	5,55E+01	5,6%
Climate change [kg CO2 eq.]	7,76E+03	19,1%
Eutrophication: freshwater [kg P eq.]	2,55E+00	2,6%
Eutrophication: marine [kg N eq.]	2,83E+01	2,7%
Eutrophication: terrestrial [Mole of N eq.]	1,77E+02	3,4%
Freshwater ecotoxicity [CTUe]	1,18E+04	1,8%
Human toxicity: cancer [CTUh]	3,85E-05	2,0%
Human toxicity: non-cancer [CTUh]	4,75E-04	1,7%
Land use [kg C deficit eq.]	5,43E+06	7,2%
Ozone depletion [kg CFC-11 eq.]	2,34E-02	5,7%
Particulate matter [Deaths]	6,37E-04	8,1%
Photochemical ozone formation [kg NMVOC eq.]	4,06E+01	4,3%
Resource use: energy carriers [MJ]	6,53E+04	7,5%
Resource use: minerals and metals [kg Sb eq.]	5,79E-02	6,8%
Water scarcity [m^3 world equiv.]	1,15E+04	7,8%
Biodiversity[a] [species loss]	3,68E-10	13,7%
Ionizing radiation[b]	0	0,0%

Legend:

a) Biodiversity is an additional impact category incorporated into the weighting scheme used in the AgBalance® Model
b) Ionizing Radiation is excluded from the weighting scheme used in the AgBalance® Model.

Figure 4-20 shows the normalized and weighted environmental impacts. It is striking that the water scarcity impact has such a significant contribution to the aggregated environmental impact of the Project Farm. As the benchmark is not irrigating, water scarcity does not contribute to the overall score of the Benchmark. The water scarcity impact leads to an overall higher environmental impact of the Project Farm than the Benchmark.

Besides water scarcity, the indicators ecotoxicity freshwater and human toxicity non-cancer show higher results for the Project Farm, which results from the amount and kind of CPA used (see section 4.1). In all other impact categories the Project Farm shows a better environmental profile.

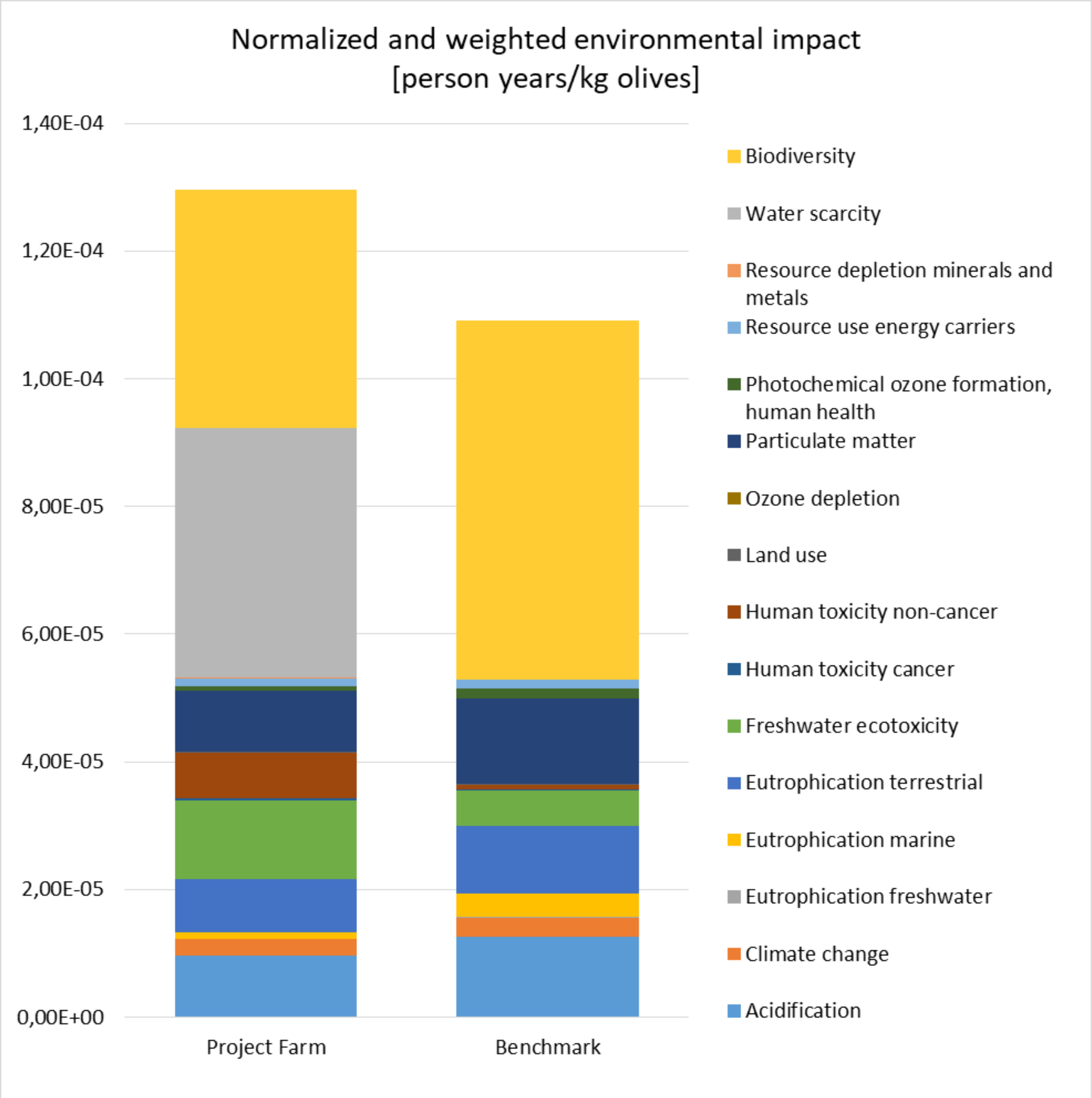

Figure 4-20 Aggregated normalized and weighted environmental impact per kg of olives at field border

Figure 4-21 shows a visualization of the economic result versus the environmental results. These economic and environmental scores depict a relative eco-efficiency comparison between the alternatives.

Normalized and weighted results of the environmental assessment are used, as well as normalized economic result for profit. It is important to mention, that the scores are a relative indication of performance among the analyzed alternatives and not a measurement of the environmental impact or the economic results in absolute terms. The closer the balls are to the upper right corner, the better the overall sustainability performance (Grosse-Sommer, Grünenwald, Paczkowski, van Gelder, & Saling, 2020).

Respective the aggregated environmental results shown in Figure 4-20, the ball representing the Benchmark is slightly closer to low impact on the environmental axis. Following the economic results, the ball representing the Project Farm is significantly closer to high results on the economic axis, leading to a better overall sustainability performance in direct comparison.

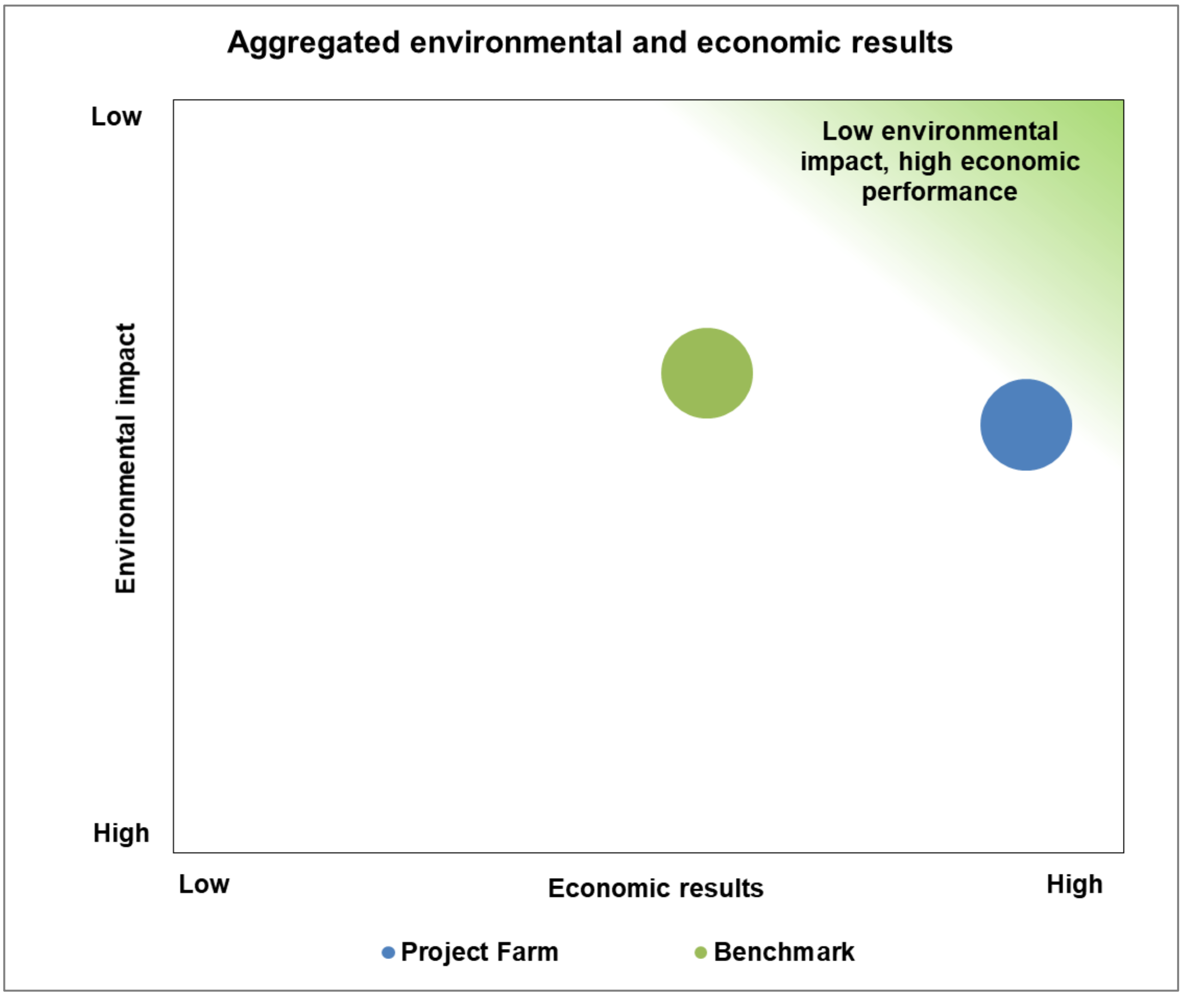

Figure 4-21 AgBalance® environmental and economic scores

As stated in section 3.4, the profit of both alternatives might be overestimated to a small degree. Hence, both bubbles might be located further to the left, what has no influence on the comparison of both alternatives.

4.3 Further Analyses

Neither a sensitivity analysis, a scenario analysis, nor an uncertainty analysis were conducted in this study.

In agricultural systems, the development of such analyses is limited by the uncertainty of the consequences of changing one system parameter (e.g. amount of irrigation, fertilizer etc.). Since there are close interactions between most of the system parameters, it is not possible to change one single parameter in a scenario analysis, for example, and leave the other parameters in their original state, since they would most likely change. Therefore, the results of one of the analyses mentioned would be accompanied by a high uncertainty, making a meaningful interpretation difficult.

4.4 LifeMax results

Table 4-2 shows the answers of both farms to the LifeMax questionnaire.

The Project Farm has a higher grass coverage and a more than twice as high percentage of land that is not treated and so can be used by wildlife. The Project Farm also has a lower Nitrogen surplus and more organic substance in the soil. As to social indicators, the Project Farm has 5 times more staff that is trained.

The Benchmark on the other hand, has a slightly higher number of bird species on the farm and a lower soil erosion. The Benchmark Farm does not use irrigation.

Beside those differences, the other questions were answered identically by both farms.

Table 4-2 Results of the qualitative LifeMax questionnaire

Indicator	Compartment	Unit	Project Farm	Benchmark
Coverage with local varieties % vs. total area	Biodiversity	%	100	100
Grass coverage% vs. total area	Biodiversity	%	80	40
Number of bird species that use the space of the sustainable olive grove for nesting, feeding or resting	Biodiversity	no	84	87
Percentage of land non-cultivated that can be used by wildlife.	Biodiversity	%	95	40
Nitrogen surplus	Soil	[kg-N]	0,0032	0,0063
Percentage of organic substance in the soil	Soil	[%]	1,2	0,8
Is the water tested before used (irrigation water, plant protection)	Product safety	yes/no	YES	Non Irrigated
Number of active substances / sample on final product (harvested olives)	Product safety	[no.]	0	0
Number of staff trainings	Social	[no.]	2	2
Number of trained staff	Social	[no.]	15	3
Protection measures while applying crop protection	Social	yes/no	YES	YES

5. Interpretation

5.1. Identification of Relevant Findings

5.1.1. LCIA results

In the majority of the assessed impact categories the "sustainable olive grove project farm" shows a better environmental profile than the benchmark.

The Project Farm shows a higher environmental footprint in the impact categories that are derived from the provision and use of Crop Protection Agents like Freshwater Ecotoxicity, Human Toxicity non-cancer, Abiotic Depletion Potential (elements) and Ozone depletion.

Due to the installed irrigation the Project Farm also shows a high footprint in the water scarcity impact.

Even as the difference calculated by the Biodiversity calculator based on the chosen field interventions is only marginal, the Project Farm's biodiversity impact is significantly lower.

5.1.2. Normalized and weighted LCIA results

As water scarcity is weighted considerably high in the BASF weighting scheme, the contribution of the irrigation on the aggregated results is significant. If irrigation would not be taken into account, the Project Farm would in total have a lower aggregated environmental impact than the Benchmark.

5.2. LifeMax Results

So far, the expertise and experience with the LifeMax questions in combination with AgBalance® is still limited. Further steps to interpret the results in relation to the results derived from AgBalance® will be developed, based on this study.

5.3. Assumptions and Limitations

The use of generic CPA datasets has only little impact on most of the assessed impact categories. As the impacts caused by the CPA production itself almost completely derive from the glyphosate production, which is available in the database, the representativeness is assumed to be good. Using the specific USEtox CFs for the calculation of the toxicity categories concretizes the results and improves the correctness of the data.

For the biodiversity assessment, assumptions were made, as the data availability was limited. Because biodiversity is considered to be of great importance, the conservative approach was chosen to not overestimate the field interventions. This keeps the data closer to the CFs calculated by Chaudhary and Brooks (2018), which is assumed to be a good proxy.

5.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2019 database were used. The LCI datasets from the GaBi 2019 database are widely distributed and used with the GaBi 9 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.4.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. The primary data received for the energy demand of the irrigation pump could not be verified as plausible. For this study, the energy demand was calculated with the generic irrigation pump that is implemented in the AgBalance® Model. The deviation between the primary value and the calculated value was more than factor ten. The precision of the generic irrigation pump calculation was confirmed by Sphera's internal water assessment expert.

  Variations across different manufacturers were balanced out by using yearly averages. All background data are sourced from GaBi databases with the documented precision.

- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the production period 2019-2020. All secondary data come from the GaBi 2019 databases and are representative of the years 2015-2018. As the study intended to compare the product systems for the reference years 2019-2020, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.5. Model Completeness and Consistency

5.5.1. Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.5.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimised by predominantly using LCI data from the GaBi 2019 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6. Conclusions, Limitations, and Outlook

5.6.1. Conclusions on the LCIA results

For this study two different ways of growing olives were compared quantitatively according to their environmental and economic sustainability performance. Additionally, social indicators were assessed in a qualitative way using the LifeMax questionnaire.

The "sustainable olive grove project farm" (called Project Farm) differs from the used Benchmark by using more and different crop protection agents, installing irrigation to ensure water supply and ensuring nutrient supply by using more fertilizer. All these measures result in a higher yield of the Project Farm. For most of the environmental impact categories this higher yield results in less environmental impact per kg olives.

However, in those impact categories that are calculated based on the impacts of the provision and use of Crop Protection Agents like Freshwater Ecotoxicity, Human Toxicity non-cancer, Abiotic Depletion Potential (elements) and Ozone depletion, the Project Farm shows a higher impact on the environment despite the higher yield and underlines the importance of finding the balance between CPA amount applied and yield. It has to be mentioned, however, that the results are a temporally snapshot representing the year 2019. In each growing season, it is possible that specific factors influence the yield that can be totally different the next year (e.g. droughts, low temperatures etc.). In 2019, fruit fly populations in the project farm were very high which required an increased use of insecticides compared to an average year.

The same applies for the impact on water scarcity. Due to the different climatic conditions that prevail despite being in the same ecoregion resulting in less precipitation (see Table 3-2), the Project Farm has to irrigate the olive grove to sustain its yield.

Impact categories that are driven by the use of fertilizers like Acidification, Eutrophication Freshwater, Marine and Terrestrial as well as Climate Change demonstrate a lower environmental impact even though the amount of fertilizer used is higher on the Project Farm. One the one hand the higher yield of the Project Farm contributes to this effect, but also the fact that the Project Farm demonstrates an almost closed Nitrogen-balance (see Figure 4-1) leads to less environmental burdens coming from the nitrogen fertilizer application in these impact categories. For the harvest 2019/2020 the nutrient balance shows that not enough fertilizer was applied by the Benchmark which in the long run will result in lower yields due to lower soil quality as more nutrients are withdrawn than are provided.

Furthermore, the Project Farm sets a focus biodiversity by giving more land to wildlife.

Overall, optimizing the production system towards a higher yield per hectare – best with a similar use of input materials – is environmentally (and of course economically) beneficial.

5.6.2. Conclusions on the optional assessments

The assessment of the eco-efficiency (environmental vs. economic performance) demonstrates that the Project Farm overall shows a better sustainability performance than the benchmark. This is backed by the social assessment from LifeMax as the number of trained staff is higher than in the benchmark. Resulting in better overall values in social and economic performance and only a slightly higher environmental impact (see also Figure 4-21).

As described above this higher environmental impact results mainly from the irrigation system of the Project Farm and should be treated with caution as the Benchmark does not irrigate at all.

The uncertainty regarding the olive revenue has no impact on the comparison, as both revenues are assumed to be overestimated in the same range.

5.6.3. Outlook

In coming studies, the LifeMax results have to be combined with AgBalance® in order to analyze more precisely the Biodiversity contribution of the Project Farm. For the creation of a standard based on AgBalance® and LifeMax this study serves as a first step.

There are several possibilities to investigate the effect of different environmental measures on the olive farms. For example, drop water irrigation compared to the existing irrigation system, the replacement of glyphosate etc.. Furthermore, the calculation of break-evens regarding yield and irrigation, fertilization etc., could be investigated.

In order to make the results more comparable a second benchmark with a farm located in an area with comparable precipitation rates and an irrigation system should be created. Otherwise a direct comparison of different farm management systems is diluted by different local conditions.

It would be interesting to see the effect of the farm management practices on the olive oil production. Including the further processing steps of the harvested olives should be considered in the follow up study.

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A.1 Critical Review Statement

Prof. Dr. Markus Frank

Review Statement and Conclusions

Taken together, the study titled “Life Max Sustainable Olive Oil –Pilot Study on Olive Cultivation” is in conformance with ISO 14040 and ISO 14044 as far as the LCA study utilizing the AgBalance® methodology is concerned. The structure of the study report is fully comprehensive and no objections to the communication of the AgBalance® study are stated. For a comparative assertion, additional information regarding the initial philosophy of both alternatives and additional information on the weighting approach are required.

The “Life Max” assessment is out of scope of ISO14040 and 14044, and additional information would be required to critically review the approach taken by the study authors.

Prof. Konstantinos Stafylidis

Review Statement

The data source file was well documented with all the necessary data needed to complete a comprehensive LCA.

The report was well documented according to ISO 14040 & ISO 14044.

The four phases of the LCA study were well defined. The goal and scope of the study were adequately defined. The LCI phase of the was carried out according to ISO 14040. The collected data met the goal of the LCA study. The results of the LCI were accessed accordingly through the LCIA phase and their environmental significance was calculated. The results of the previous phases were summarized and discussed in depth.

The data collection form was complete, although the data validation was not documented. The impact categories used in the report were adequate for the nature of the farm’s activities.

The LCA has met the requirements for methodology, data, interpretation and reporting and is consistent with the principles of the ISO standards.

Conclusions

The LCA study uses a well-established scientific approach to evaluate all the critical impacts categories. The methods used to carry out the LCA were consistent with ISO 14040 & ISO 14044. The methods used to carry out the LCA were scientifically and technically valid. The data used were appropriate and reasonable in relation to the goal of the study. The interpretations reflected the limitations identified and the goal of the study and the study report was transparent and consistent.

Prof. Georgios Nanos

Review Statement

The experienced personnel to collect and calculate field data and to develop the environmental study were sufficient to complete a thorough useful, but 1 year only, study. The analysis of field data gives insights in all environmental aspects included in ISO 14040 and ISO 14044 plus additional certified from other sources aspects used from BASF SE including a biodiversity and an economic assessment. The study is complete for field production of olives (up to farm gate) with some, mainly minor, matters to be improved based on the Comments stated above for the Data Base and the Report presented to me.

Conclusions

Very useful study a) giving an environmentally - friendly and economically – acceptable approach to cultivate olives, b) pointing out the cultivation practices mainly affecting the environmental footprint of the crop, thus allowing for manipulations to further improve cultivation and the environmental footprint, and c) offering a tool to certify olive cultivation to improve its commercial value and its market position.

B.1 Emissions into air, water and soil

Table B-1 Nitrogen-based air emissions: applied methods and emission sources

Emission sources	Region	Climate	Formulas and factors	Reference
Nitrogen oxide NO_x				
Organic and mineral fertilizer	E[a)]	-	0,011 kg NO_x-N / kg N (cropland)	(Stehfest & Bouwman, 2006)
Organic and mineral fertilizer	W[b)]	-	0,012 kg NO_x-N / kg N (cropland)	(Stehfest & Bouwman, 2006)
Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation Nitrogen from excretions from draft animals	E	-	0,011 kg NOx-N / kg N (cropland) assumed as mineral and organic fertilizer from Bouwman 2006	Assumed as (Stehfest & Bouwman, 2006)
Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation Nitrogen from excretions from draft animals	W	-	0,012 kg NOx-N / kg N (cropland) assumed as mineral and organic fertilizer from Bouwman 2006	Assumed as (Stehfest & Bouwman, 2006)
Diesel combustion in a tractor	E/W	-	(77,488-42,963*Umin-21,451*power-3,352*Umin*Umin+22,886*Umin*power+6,362*power*power)/1000 kg NOx/kg diesel Umin: share of nominal engine speed [-] (ts assumption= 0,5) power: share of nominal power [-] (ts assumption= 0,5)	(Rinaldi & Stadtler, 2002)
Diesel combustion in an irrigation pump	E/W	-	0,0713 kg NO_x/kg diesel	ts dataset "Irrigation pump generic" (thinkstep AG, 2019)
Biomass combustion	W	-	(Ncont*100*9,5-0,49)/1000 kg NOx/kg biomass Ncont- N content of combusted biomass (fresh mass) [kg/kg]	ts dataset "Biomass combustion (field)" based on (Battye & Battye, 2002) (thinkstep AG, 2019)
Nitrous oxide N_2O (direct)				
Mineral fertilizer	E/W	Wet[c)]	0,016 kg N_2O-N/kg N	(IPCC, 2019)
		Dry[c)]	0,005 kg N_2O-N/kg N	
		Aggregated	0,01 kg N_2O-N/kg N	
Organic fertilizer Above and below ground residues Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation	E/W	Wet	0,006 kg N_2O-N/kg N	(IPCC, 2019)
		Dry	0,005 kg N_2O-N/kg N	
		Aggregated	0,01 kg N_2O-N/kg N	
Nitrogen from excretions of draft animals	E/W	Wet	0,006 kg N_2O-N/kg N	(IPCC, 2019)
		Dry	0,002 kg N_2O-N/kg N	
		Aggregated	0,004 kg N_2O-N/kg N	

Diesel combustion in an agricultural tractor	E/W	-	0,0002325 kg N_2O/kg diesel	Assumption from "diesel, burned in agricultural machinery" Ecoinvent 3.4
Diesel combustion in an irrigation pump	E/W	-	0,000256 kg N_2O/kg diesel	ts dataset "Irrigation pump generic" (thinkstep AG, 2019)
Emission sources	**Region**	**Climate**	**Formulas and factors**	**Reference**
		Nitrous oxide N_2O (indirect)		
Nitrogen oxides NO_x	E/W	Wet	0,014 kg of the volatilized nitrogen in nitrogen oxides (NO_x-N)	(IPCC, 2019)
		Dry	0,05 kg of the volatilized nitrogen in nitrogen oxides (NO_x-N)	
		Aggregated	0,01 kg of the volatilized nitrogen in nitrogen oxides (NO_x-N)	
Ammonia NH_3	E/W	Wet	0,014 kg of the volatilized nitrogen in ammonia (NH_3-N)	
		Dry	0,05 kg of the volatilized nitrogen in ammonia (NH_3-N)	
		Aggregated	0,01 kg of the volatilized nitrogen in ammonia (NH_3-N)	
Nitrate (NO_3^-)	E/W		0,0011 kg of the leached nitrogen (NO_3-N)	
		Ammonia NH_3		
Mineral fertilizer	E	Climatic differentiation	Factors are available for the following fertilizers: anhydrous ammonia, ammonium sulphate, ammonium sulphate urea, ammonium nitrate, ammonia solution, calcium ammonium nitrate, calcium nitrate, di-ammonium phosphate, mono-ammonium phosphate, urea, urea ammonium nitrate and NPK mixtures. See also Annex Table B-2 differentiated according fertilizer type, soil pH and climate	(EMEP/EEA, 2016)
Mineral fertilizer	W		0,11 kg NH_3-N /kg N[d)]	(IPCC, 2019)
Organic fertilizer Nitrogen from excretions of draft animals	E/W	-	0,21 kg NH_3-N / kg N	(IPCC, 2019)
Soil mineral nitrogen Nitrogen in legumes Nitrogen from irrigation Nitrogen from precipitation	E/W	-	Assumed as 0,11 kg NH_3-N / kg N (emission factor for mineral fertilizers from IPCC 2019)	Assumed as (IPCC, 2019)
Biomass combustion	E/W	-	(961-984*CE)/1000*0,014 [kg NH_3/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average of forest and grass combustion efficiencies	ts dataset "Biomass combustion (field)" based on (Battye & Battye, 2002) (thinkstep AG, 2019)

Legend:

a) E: European region

b) W: World

c) For the definition of wet and dry climate see (IPCC, 2019)

d) The emission factor as stated in the (IPCC, 2019) consists of an emission factor for both NH_3 and NO_x, equivalent to 0,11 kg (NH_3-N + NO_x-N) / kg applied N. However, following the approach of the Product Environmental Footprint Category Rules (PEFCR) (European Commission, 2017), the ASP (AgBalance® Sustainability Expert Panel: panel of at least three AgBalance® Sustainability Experts (3 ASE) (Ulrich, Stenull, Schulze, & Frank, 2019)) assumed that this factor is applicable to calculate NH_3 emissions excluding the NOx emissions.

Table B-2 Emissions factors for NH3 from mineral fertilizers (European region)

Table 3.2 EFs for NH_3 emissions from fertilisers (in g NH_3 (kg N applied)$^{-1}$)

	Climate					
	Cool		Temperate		Warm	
	normal pH ([a])	high pH ([b])	normal pH ([a])	high pH ([b])	normal pH ([a])	high pH ([b])
Anhydrous ammonia (AH)	19	35	20	36	25	46
AN	15	32	16	33	20	41
Ammonium phosphate (AP) ([c])	50	91	51	94	64	117
AS	90	165	92	170	115	212
CAN	8	17	8	17	10	21
NK mixtures ([d])	15	32	22	33	20	41
NPK mixtures ([d])	50	91	67	94	64	117
NP mixtures ([d])	50	91	67	94	64	117
N solutions ([e])	98	95	100	97	126	122
Other straight N compounds ([f])	10	19	14	20	13	25
Urea[(g)]	155	164	159	168	198	210

([a]) A 'normal' pH is a pH of 7.0 or below.
([b]) A 'high' pH is a pH of more than 7.0 (usually calcareous soils).
([c]) AP is the sum of ammonium monophosphate (MAP) and diammonium phosphate (DAP).
([d]) NK mixtures are equivalent to AN, NPK and NP mixtures, which are 50 % MAP plus 50 % DAP.
([e]) N solutions are equivalent to urea AN.
([f]) Other straight N compounds and equivalent to calcium nitrate.
(g) Urea is an organic compound with the chemical formula $CO(NH_2)_2$.

Table B-3 Emissions factors for other air emissions (European region)

Substance	Emission source	Factor	Reference
NMVOC	Diesel combustion in tractor	((22,432-43,165*Umin-11,93*power+ 26,628*Umin*Umin+ 2,06*Umin*power+6,505*power*power)/1000) [in kg NMVOC/kg diesel] Umin: share of nominal engine speed [-] (ts assumption= 0,5) power: share of nominal power [-] (ts assumption= 0,5)	(Rinaldi & Stadtler, 2002)
	Diesel combustion in irrigation pump	0,00192 [kg NMVOC/kg diesel]	(thinkstep AG, 2019)
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Agricultural products	0,86 [kg NMVOC/ha]	(EMEP/EEA, 2016)
	Biomass combustion	(961-984*CE)/1000*combusted biomass*0,085 [kg NMVOC/ha] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies combusted biomass amount in [kg/ha]	(Battye & Battye, 2002)

Substance	Emission source	Factor	Reference
$PM_{2,5}$ PM_{10}	Diesel combustion in tractor	0,003 [kg $PM_{2,5}$/ kg diesel]	(thinkstep AG, 2019)
	Diesel combustion in irrigation pump	0,003*diesel [kg $PM_{2,5}$/kg diesel]	(thinkstep AG, 2019)
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Natural sources: harvesting and soil cultivation	1,5 kg/ha [kg PM_{10}/ha] 0,06 kg/ha [kg $PM_{2,5}$/ha]	(EMEP/EEA, 2016)
	Biomass combustion	(67,4-66,8*CE)/1000 [kg $PM_{2,5}$/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies Combusted biomass amount in fresh matter	(Battye & Battye, 2002)
CO	Diesel combustion in tractor	((55,923-140,688*Umin+16,603*power+102,643* Umin*Umin67,597*Umin*power+44,545* power* power)/1000) Umin: share of nominal engine speed [-] (ts assumption= 0,5) power: share of nominal power [-] (ts assumption= 0,5)	(Rinaldi & Stadtler, 2002)
	Diesel combustion in irrigation pump	0,0192*diesel [kg CO/ha] diesel: amount of diesel [kg/ha]	(thinkstep AG, 2019)
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets, see Table 3-6
	Biomass combustion	(961-984*CE)/1000 [kg CO/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies Combusted biomass amount in fresh matter	(Battye & Battye, 2002)

Substance	Emission source	Factor	Reference
CO_2	Diesel combustion in tractor	3,17 [kg CO_2/kg diesel]	(Statistics Norway, 2019)
	Diesel combustion in irrigation pump	3,14 [kg CO_2/kg diesel]	(thinkstep AG, 2019)
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets, see Table 3-6
	Urea fertilizer application	0,2*44/12 [kg CO_2/kg applied urea fertilizer]	(IPCC, 2006)
	Limestone application	0,12*44/12 [kg CO_2/kg applied limestone]	(IPCC, 2006)
	Dolomite fertilizer application	0,13*44/12 [kg CO_2/kg applied dolomite]	(IPCC, 2006)
	Calcium ammonium nitrate fertilizer application	(0,12/0,56)*0,12*44/12 [kg CO_2/kg applied CAN fertilizer]	Assumption of ASE. Conversion of CaO content to CaCO3 content using molecular mass. Amount of CaCO3 in calcium ammonium nitrate (CAN) is multiplied by emission factor of 12%, also used for limestone, equivalent to the carbon content of the CaCO3 according to (IPCC, 2006). CaO content of fertilizer from (YARA GmbH & Co. KG, 2018)
	Urea ammonium nitrate fertilizer application	(0,15/0,46)*0,2*44/12 [kg CO_2/kg applied UAN fertilizer]	ASE. Conversion of nitrogen content in the form of urea in urea ammonium nitrate (UAN) into amount of urea, using the content of nitrogen of urea fertilizers (46%). Amount of urea in urea ammonium nitrate is multiplied by emission factor of 20%, also used for urea, equivalent to the carbon content of urea according to IPCC. N content of fertilizer from (Fritsch, 2012)
	Biomass combustion	CE*carbon content[a)]*44/12 [kg CO_2/kg combusted biomass] CE: combustion efficiency [-],0,92 (ts assumption as average) carbon content: carbon content of biomass in fresh matter [kg C/kg biomass], default value: 0,54[a)]	(Battye & Battye, 2002)
CH_4	Diesel combustion in tractor	0,000012 [kg CH_4/kg diesel]	(Statistics Norway, 2019)
	Diesel combustion in irrigation pump	0,000214 [kg CH_4/kg diesel]	(thinkstep AG, 2019)
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets, see Table 3-6
	Draft animals (net energy, enteric fermentation and pasture/grazing)	not applicable	(IPCC, 2019)
	Rice flooding		(IPCC, 2006)
	Biomass combustion	(42,7-43,2*0,92)/1000 [kg CH_4/kg combusted biomass] combusted biomass amount in fresh matter	(Battye & Battye, 2002)
Halogenated hydrocarbons	Biomass combustion	0,000053 [kg $CHCl_3$/kg combusted biomass]	(Battye & Battye, 2002)

Substance	Emission source	Factor	Reference
SO_2	Diesel combustion in tractor	0,0000156 [kg SO_2/kg diesel]	(Statistics Norway, 2019)
	Diesel combustion in irrigation pump	0,00005 [kg SO_2/kg diesel]	(thinkstep AG, 2019)
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets, see Table 3-6
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Biomass combustion	0,001 [kg SO_2/kg combusted biomass] Combusted biomass amount in fresh matter	(Battye & Battye, 2002)
Benzo{a}pyrene	Diesel combustion in tractor	150*42,7*0,835/(1E-12) [kg benzo{a}pyrene/kg diesel]	(thinkstep AG, 2019)
	Fertilizer production	Fertilizer specific	Emissions modeled through the respective datasets, see Table 3-6
	Electricity production	Country specific electricity grid mix	BASF LCI database
	Biomass combustion	(67,4-66,8*CE/1000)*1,4E-5 [kg benzo{a} pyrene/kg combusted biomass] CE: combustion efficiency [-], ts assumption 0,92 as average between forest and grass combustion efficiencies Combusted biomass amount in fresh matter	(Battye & Battye, 2002)

C.1 Detailed impact category descriptions

Table C-4 Detailed impact category descriptions

Impact Category	Description	Unit	Reference
Biodiversity	Combined measure of prediction of potential global species loss of 5 taxa per unit of area of 804 ecoregions, for occupation and transformation of 5 land use types and three levels of intensity and an evaluation of the effectiveness and certainty of different conservation interventions.	Global lost species equivalent	(Chaudhary & Brooks, 2018)and (Dicks & Ashpole, 2014)
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	(IPCC, 2013)
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	moles H^+ equivalent	(Seppälä J., 2006; Posch M. S., 2008)
Eutrophication (terrestrial, freshwater, marine)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	Terrestrial: moles N equivalent Freshwater: kg P equivalent Marine: kg N equivalent	(Seppälä J., 2006; Posch M. S., 2008; Struijs J. B., 2009)
Ozone Depletion	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion	kg CFC-11 equivalent	(Guinée, et al., 2002)

Impact Category	Description	Unit	Reference
	of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants.		
Photochemical Ozone Formation	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg C_2H_4 equivalent	(Van Zelm R., 441-453)
Resource use, minerals and metals	The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Depletion of mineral resources and non-renewable energy resources are reported separately. Depletion of mineral resources is assessed based on ultimate reserves.	kg Sb equivalent, MJ (net calorific value)	(Guinée, et al., 2002)
Resource use, energy carriers	A measure of the total amount of non-renewable primary energy extracted from the earth. Resource use is expressed in energy demand from non-renewable resources including both fossil sources (e.g. petroleum, natural gas, etc.) and uranium for nuclear fuel. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ	(Guinée, et al., 2002; van Oers, de Koning, Guinée, & Huppes, 2002)
Respiratory inorganics	Particulate matter emissions and secondary aerosols formed in the atmosphere from NOx, NH3 and SO2 emissions contribute to human health impacts in the form of respiratory disease and related effects.	Disease incidence	(Fantke P. E., 2016)
Soil organic matter (SOM) / Land use	A measure of the content of organic material in soil. This derives from plants and animals and comprises all of the organic matter in the soil exclusive of the matter that has not decayed.	kg C deficit	(Milà i Canals, Romanyà, & Cowell, 2007)
Human toxicity Eco-toxicity	A measure of toxic emissions which are directly harmful to the health of humans and other species.	Comparative toxic units (CTU_h, CTU_e)	(Rosenbaum R. K., et al., 2008)

Impact Category	Description	Unit	Reference
Water Use	An assessment of water scarcity accounting for the net intake and release of fresh water across the life of the product system considering the availability of water in different regions.	User Deprivation Potential (UDP) in m^3 world-equivalents	(Boulay, et al., 2018)